NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

TRANSFORMATIONAL COMMUNICATIONS ARCHITECTURE FOR THE UNIT OPERATIONS CENTER (UOC); COMMON AVIATION COMMAND AND CONTROL SYSTEM (CAC2S); AND COMMAND AND CONTROL ON-THE-MOVE NETWORK, DIGITAL OVER-THE-HORIZON RELAY (CONDOR)

by

Gilbert O. Garcia
David C. Joseforsky

June 2004

Thesis Co-Advisor:	Bill Kemple
Thesis Co-Advisor:	Brian Steckler

Approved for public release; distribution is unlimited.

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2004	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE: Transformational Communications Architecture for the Unit Operations Center (UOC); Common Aviation Command and Control System (CAC2S); and Command and Control On-the-Move Network, Digital Over-the-Horizon Relay (CoNDOR)	**5. FUNDING NUMBERS** RISHV, RISHM, BCD01, ROR3A
6. AUTHOR(S) Gilbert O. Garcia and David C. Joseforsky	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) Marine Corps Systems Command Quantico, Va. 22554-5010	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

The purpose of this research was to introduce a Transformational Communications Architecture for the Unit Operations Center (UOC); Common Aviation Command and Control System (CAC2S); and Command and Control On-the-Move Network, Digital Over-the-Horizon Relay (CoNDOR).

The methodology used was to conduct Field Tests with government contractors and private vendors in order to demonstrate the capabilities of each wireless technology researched. These wireless technologies, Free Space Optics (FSO), Microwave, 802.16, 802.11b over SecNet-11, Orthogonal Frequency Division Multiplexing (OFDM), Broadband Satellite, INMARSAT, and Iridium, all have the potential of being implemented in the transformational communications architecture for intra-nodal and inter-nodal links for UOC and CAC2S, as well as the CoNDOR communications architecture. The ultimate goal of this research was to introduce different technologies that offer more flexibility, mobility, and capability at the tactical level giving the Marine Corps the tactical wireless edge.

Throughout this research, the focus revolved around testing equipment and network configurations in an IP network. Special consideration was given to wireless issues for the UOC, CAC2S, and CoNDOR, which could improve line-of-sight, beyond line-of-sight, and over-the-horizon communications for each program. These new technologies will transform communications in the United States Marine Corps for the 21st century.

14. SUBJECT TERMS UOC, CAC2S, CoNDOR, FSO, 802.11b, SecNet-11, 802.16, OFDM, Microwave, SATCOM, INMARSAT, IRIDIUM, KG-235, LOS, BLOS, OTH, Communications on-the-move, and FORCEnet	**15. NUMBER OF PAGES** 276
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited.

TRANSFORMATIONAL COMMUNICATIONS ARCHITECTURE FOR THE UNIT OPERATIONS CENTER (UOC); COMMON AVIATION COMMAND AND CONTROL SYSTEM (CAC2S); AND COMMAND AND CONTROL ON-THE-MOVE NETWORK, DIGITAL OVER-THE-HORIZON RELAY (CONDOR)

Gilbert O. Garcia
Captain, United States Marine Corps
B.S., The Citadel, 1995

David C. Joseforsky
Captain, United States Marine Corps
B.S., United States Naval Academy, 1997

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY

from the

NAVAL POSTGRADUATE SCHOOL
June 2004

Authors: Gilbert O. Garcia and David C. Joseforsky

Approved by:

William Kemple
Co-Advisor

Brian Steckler
Co-Advisor

Dan Boger
Chairman, Department of Information Sciences

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The purpose of this research was to introduce a Transformational Communications Architecture for the Unit Operations Center (UOC); Common Aviation Command and Control System (CAC2S); and Command and Control On-the-Move Network, Digital Over-the-Horizon Relay (CoNDOR).

The methodology used was to conduct Field Tests with government contractors and private vendors in order to demonstrate the capabilities of each wireless technology researched. These wireless technologies, Free Space Optics (FSO), Microwave, 802.16, 802.11b over SecNet-11, Orthogonal Frequency Division Multiplexing (OFDM), Broadband Satellite, INMARSAT, and Iridium, all have the potential of being implemented in the transformational communications architecture for intra-nodal and inter-nodal links for UOC and CAC2S, as well as the CoNDOR communications architecture. The ultimate goal of this research was to introduce different technologies that offer more flexibility, mobility, and capability at the tactical level giving the Marine Corps the tactical wireless edge.

Throughout this research, the focus revolved around testing equipment and network configurations in an IP network. Special consideration was given to wireless issues for the UOC, CAC2S, and CoNDOR, which could improve line-of-sight, beyond line-of-sight, and over-the-horizon communications for each program. These new technologies will transform communications in the United States Marine Corps for the 21st century.

THIS PAGE INTENTIONALLY LEFT BLANK

THESIS ROADMAP

For readers who need a quick explanation of this thesis research, read the executive summary, conclusions, and recommendations. The reader will find the thesis in the following order: table of contents, list of figures, list of tables, acknowledgements, executive summary, Chapter I (Introduction), Chapter II (Field Tests), Chapter III (Findings and Analysis), Chapter IV (Conclusions), Chapter V (Recommendations), Appendix, list of acronyms, and initial distribution list.

Chapter I discusses the problem and background information on UOC, CAC2S, and CoNDOR. The problem addresses the fundamental reason for conducting this thesis research, and the background information gives a summary of the different programs that are being studied.

Chapter II explains in detail how each field test was conducted. This chapter only discusses the procedures of each field test. For results of each test, the reader must read Chapter III (Findings and Analysis). Chapter III summarizes the results of the four field tests and gives detailed findings and analysis.

Chapter IV discusses the conclusions for the UOC, CAC2S, and CoNDOR programs. In this chapter, the technologies examined are associated with the potential use in each program.

Chapter V provides recommendations for the UOC, CAC2S, and CoNDOR programs. The reader can learn what can be implemented now in each program. In addition, the reader can find out what could be implemented in the future for each program, how this research ties into a FORCEnet application, and what can be done as follow-on research.

The Appendix contains a summary of each product used in this thesis research and supplemental information that further assists the reader while reading the paper.

Finally, the thesis ends with a list of acronyms and an initial distribution list.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

As the authors of this research project, we were overwhelmed by the support provided from each company that worked with us over the past six months. Every single company played a significant role in our research ventures, so we want to say thank you to every company for the trust they placed in us to evaluate their technology for potential future use in the Marine Corps.

The following companies provided support and personnel assistance during the respective testing evolutions:

Backyard Testing in Monterey, CA area (November 17-21, 2003): fSONA, Lightpointe

General Dynamics Testing in Scottsdale, AZ (January 5-9, 2004): General Dynamics Decision Systems, fSONA, MRV Communications, Ensemble Communications, Lightpointe, and Cisco Systems

Special thanks to Don Lesmeister, Mark "Tracker" Hanson, Mike Fallon, and Pattie Fekete from General Dynamics who all made this event run so seamlessly. The team you put together was first class! In addition, LTC Doug Larson and Maj Ben Luoma deserve recognition for their logistic support at Papago Army National Guard Base.

Raytheon Testing in San Diego, CA (February 2-6, 2004): Raytheon Integrated Defense Systems, Harris Corporation, Lightpointe, Ensemble Communications, Terabeam, MRV Communications, General Dynamics Decision Systems, fSONA, Alvarion, Segovia, and Cisco Systems

Special thanks to John Harmon, Phil Benham, and Fajed Bouomar at Raytheon who helped plan and coordinate our testing evolution. We could not have succeeded without your time and energy. Next, Captain Eric Smith and his Marines from Marine Air Support Squadron 6 provided unbelievable support throughout the testing conducted on Miramar Air Station.

Field Testing at Camp Roberts, CA (March 7-11, 2004): Lightpointe, Terabeam, Redline Communications, Alvarion, Segovia, Omega Systems, Nera, MLB Company, fSONA, Western Datacom, and Cisco Systems

There are numerous individuals we want to recognize for their support during this event. John Kalina from Monterey Peninsula College was an incredible supporter during this venture. Thank you for devoting so much of your time to us, providing vital networking equipment, and mentoring us. Our network would have been inoperable without the assistance of Ross Warren from Segovia. Thank you for your dedication to mission accomplishment! Next, Kevin Jones from the Naval Postgraduate School hand built the platforms for the balloon and Unmanned Aerial Vehicle. Your knowledge and time were very much appreciated. Finally, Marine Air Support Squadron 6 once again provided equipment and a team of well-trained Marines. Thank you for staying the course to support us despite the many obstacles we encountered.

To our two friends, LT Manny Cordero and LT Al Seeman, who joined forces with us during all these testing events, you both made these last few months among the most memorable times of our lives. Thank you for your friendship, dedication, time, energy, discipline, and sense of humor.

In addition, our thesis objectives could not have been accomplished without sponsors to support our work and provide funding. Thanks go out to Marine Corps Systems Command, Space and Naval Warfare Systems Command (SPAWAR), and the following individuals at the Naval Postgraduate School: Dr. David Netzer, Captain Jeff Kline, USN, Professor Brian Steckler, and Dr. Bill Kemple. We appreciate the trust and confidence you placed in us to accomplish our thesis research.

Finally, the advice and support we received from our technical sponsor, Mr. Dennis Gette, SPAWAR Charleston, was truly outstanding. Thank you for the thesis topic, mentoring us, and being with us every step of the way through this process.

And to Tanya and Maria, thank you for being such loving and supportive wives during this thesis evolution.

EXECUTIVE SUMMARY

The purpose of this research was to introduce a Transformational Communications Architecture for the Unit Operations Center (UOC); Common Aviation Command and Control System (CAC2S); and Command and Control On-the-Move Network, Digital Over-the-Horizon Relay (CoNDOR).

Through funding from Marine Corps Systems Command (MCSC) and several Naval Postgraduate School (NPS) professors, Captain Joseforsky and Captain Garcia set out in October 2003 to conduct face-to-face interviews with their sponsors and several commercial vendors that could potentially help them with their thesis work. After this trip, they formulated a plan to do 'backyard' testing of several commercial off-the-shelf technologies in the Monterey, CA area. Two months later after some intensive coordination, they went to General Dynamics in Scottsdale, AZ and Raytheon in San Diego, CA to conduct testing with the UOC and CAC2S program offices respectively. Finally, they completed their testing evolutions with a realistic tactical scenario that resembled the CoNDOR architecture at Camp Roberts, CA in March 2004.

In November 2003, Captain Joseforsky and Captain Garcia orchestrated a team (LT Jesus "Manny" Cordero and LT Al Seeman) in order to achieve individual thesis work for NPS. Overall, over 25 U.S. Government agencies, government contractors, and commercial vendors were coordinated in order to accomplish the various testing evolutions. Each of these events required detailed planning and execution in order for the companies to come in and demonstrate their technologies. The students managed to synchronize equipment to be temporarily utilized from all these companies in order to accomplish their thesis objectives.

The wireless technologies that were researched, Free Space Optics (FSO), Microwave, 802.16, 802.11b over SecNet-11, Orthogonal Frequency Division Multiplexing (OFDM), Broadband Satellite, INMARSAT, and Iridium, all have the potential of being implemented in the transformational communications architecture for intra-nodal and inter-nodal links for UOC and CAC2S, as well as the CoNDOR

communications architecture. The table below gives the Pros and Cons of each technology (Table 1). This table was the foundation for the recommendation matrix seen below.

UOC/CAC2S/CoNDOR	Distance	Pros	Cons
FSO	LOS	Fiber throughput speeds, quick setup time, operates in license free spectrum	Susceptible to weather conditions, short distance (< 5 km), laser alignment
MICROWAVE (RFM)	LOS	Up to OC-3 speeds, already packaged, reaches out to 13 kilometers	Obtain authorization for frequency use, susceptible to interception due to RF use
802.16	LOS	Adaptive modulation, up to 66 Mbps, 360 degree coverage out to 20 km	No built-in encryption, company evaluated was ATM based (there are others IP based)
802.11b over SecNet-11	LOS	Type 1 encryption built-in, send up to secret level data, small footprint	Low throughput of 1-2 Mbps, difficult to configure, not compatible with other 802.11b
OFDM	BLOS	Communicates over hills, through trees, and around buildings, 25 Mbps throughput	Limited encryption built in, need good azimuth for BLOS connectivity
BROADBAND SATELLITE (Segovia/Omega Systems)	BLOS/OTH	Large throughput capabilities of up to 9 Mbps, mountable on a vehicle, Type 1 encryption	Annual/Monthly Fees, but not by minute
INMARSAT (Nera)	BLOS/OTH	Satellite connectivity on-the-move, small mountable vehicle platform, encryption	Expensive per minute fees, low throughput of 56 Kbps (working on upgrades)
IRIDIUM	BLOS/OTH	Capable of combining four channels, comms on-the-move, no monthly fees	Low throughput of 2.4 Kbps per channel, difficult to send data without compression

Table 1. TECHNOLOGY SUMMARY

The ultimate goal of this research was to introduce different technologies that offer more flexibility, mobility, and capability at the tactical level giving the Marine Corps the tactical wireless edge. During the Field Tests conducted for this research project, the strengths and adaptability of the various products were assessed. The recommendations on how to best implement these technologies for UOC, CAC2S, and CoNDOR are given in the table below (Table 2).

UOC/CAC2S	FSO	MICROWAVE	802.16	OFDM	BROADBAND SATELLITE	INMARSAT	IRIDIUM	802.11b over SecNet-11
INTRA-NODAL								
LOS	1	2	4	3				5
BLOS				1				
INTER-NODAL								
LOS	4	3	2	1				5
BLOS				1	2	3	4	
OTH					1	2	3	
COMMS ON THE MOVE								
Within the convoy				1				2
Outside the convoy				3		1	2	
For short/long halts, refer to Inter-Nodal BLOS/OTH section								
AERIAL RELAY (UAV/BALLOON)				2				1
CoNDOR	FSO	MICROWAVE	802.16	OFDM	BROADBAND SATELLITE	INMARSAT	IRIDIUM	802.11b over SecNet-11
INTO POP-V								
LOS	1	2	4	3				5
BLOS				1	2	3	4	
OUT OF POP-V TO MSC								
BLOS				1	2	3	4	
OTH					1	2	3	
COMMS ON THE MOVE								
Within the convoy				1			3	2
Outside the convoy				3		1	2	
For short/long halts (BLOS)				1	2	3	4	
AERIAL RELAY (UAV/BALLOON)				2				1
Ranking of technologies for each program (1 = first recommendation, 2 = second recommendation…)								

Table 2. RECOMMENDATION OF WIRELESS TECHNOLOGIES

The authors decided to combine the UOC and CAC2S recommendations together since the command and control systems have similar distance requirements when physically deployed on the battlefield and the requirements for communications on-the-move are very much alike. CoNDOR's recommendations were kept separate since it is not a command and control system but rather a concept of connecting multiple echelons of command together. For UOC and CAC2S, there are four functional areas that communications requirements can fall under: intra-nodal, inter-nodal, communications on-the-move, and aerial relay. The CoNDOR concept revolves around the Point of Presence Vehicle (POP-V) so the functional areas were outlined as follows: into POP-V, out of POP-V, communications on-the-move, and aerial relay.

UOC/CAC2S

By utilizing wireless technologies to link a Command Center to Antenna Hill within a UOC node or from Processing and Display Subsystem (PDS) to Communications Subsystem (CS) and Sensor Data Subsystem (SDS) in a CAC2S node, the Marine Corps could potentially replace fiber cables that run between the sites. The intra-nodal setup is divided into two different categories for communications, LOS and BLOS. The LOS technologies researched for the intra-nodal setup in the order of recommendation are as follows: Free Space Optics (FSO), Microwave, Orthogonal Frequency Division Multiplexing (OFDM), 802.16, and 802.11b over SecNet-11. FSO is the right fit for this short distance of less than 2 kilometers due to its capabilities shown in Table 1 above. OFDM was researched and evaluated over the period of this thesis work. It has tremendous capabilities of being placed in valleys near Antenna Hill where it can be camouflaged without inhibiting the capacity of the link. The authors saw throughput up to 25 Mbps when in non-line-of-sight situations.

Since the distances between UOC and CAC2S nodes are unpredictable due to the frequent movement of units on the battlefield, line-of-sight (LOS), beyond line-of-sight (BLOS), and over-the-horizon (OTH), could all be encountered at any given time. In order of ranking, the following technologies are recommended for use in LOS situations for the inter-nodal scenario: OFDM, 802.16, Microwave, FSO, and 802.11b over SecNet-11. OFDM is best suited for this type of setup since it is the most forgiving of the technologies if ideal LOS is not attained. While all of the LOS technologies become more and more incapable of reaching BLOS distances, OFDM can operate in LOS or BLOS situations. This makes the technology the number one recommendation for inter-nodal BLOS scenarios. OFDM will maintain connectivity over hills, through trees, and around buildings. These are the rankings for OTH communications in the inter-nodal scenario: Broadband satellite, INMARSAT, and Iridium. Broadband satellite provided by Segovia/Omega Systems can replace the TRC-170 setup for CAC2S with its capabilities to reach up to 9 Mbps, and it is comparable in size with the SMART-T system, but could provide more throughput capability for the UOC node.

OFDM is the first recommendation for communications on-the-move within a convoy because LOS does not need to be maintained while the vehicles are moving. Each vehicle can remain a safe distance away from the others, which ensures a good security posture. While the distance and terrain can vary greatly when communicating from a UOC/CAC2S forward echelon convoy back to the main, some type of satellite connectivity that can function on-the-move will be needed. INMARSAT is recommended ahead of Iridium due to its throughput capabilities.

The use of aerial relays for UOC and CAC2S nodes can greatly increase inter-nodal communications. This could be an alternative to the MRC-142 or TRC-170, as the 802.11b over SecNet-11 could be retransmitted via the airborne platform for hundreds of miles if the signal was amplified and appropriate antennas were utilized. If it is determined that OFDM can be amplified, then distance could equal that of 802.11b and greater flexibility is attained on where antennas would need to be placed on the ground to maintain connectivity with the airborne platform.

CoNDOR

The current plan for the CoNDOR scenario is to place a Point of Presence Vehicle (POP-V) at the battalion level to further enhance the capabilities of the subordinate units with low throughput capabilities. This vehicle will allow those units with EPLRS, SINCGARS, HF, HF Automatic Link Establishment (ALE), and UHF SATCOM to have access to Major Subordinate Commands (MSCs) through the satellite connectivity at the battalion level.

The LOS recommendations for the communications into the POP-V resemble the LOS rankings used for UOC and CAC2S. Since EPLRS is currently the best form of data connectivity down to the lower levels at 56 Kbps, it is obvious that the technologies recommended would bring a new kind of capability down to the lowest level. The following technologies are recommended for LOS into the POP-V in the order of preference: FSO, Microwave, OFDM, 802.16, and 802.11b over SecNet-11. For BLOS situations when communicating from the lower echelons to the POP-V, the following technologies are recommended in order of preference: OFDM, Broadband Satellite, INMARSAT, and Iridium. OFDM can become the technology of the future for the Marine Corps if it can be properly encrypted in a cost effective manner.

When communicating from the POP-V to an MSC, the scenario will most likely require some form of BLOS or OTH connectivity. In a BLOS situation, the following technologies are recommended in the order of the authors preference: OFDM, Broadband satellite, INMARSAT, and Iridium. OFDM can provide a terrestrial connection up to 20 kilometers. The three technologies ranked for OTH capability are Broadband satellite, INMARSAT, and Iridium. Segovia/Omega Systems Broadband satellite connectivity during Field Test Four was most impressive. They are able to vary the amount of throughput that is needed and can provide private network capabilities, Internet services, and phone services. Their link can also be Type 1 encrypted, which could provide SIPRNET connectivity.

Communications on-the-move is what the CoNDOR architecture is built around. The following are the recommendations in order of priority for communications within the convoy: OFDM, 802.11b over SecNet-11, and Iridium. OFDM will again provide sufficient bandwidth for a platoon/company-sized unit, enable a small footprint, and allow vehicles flexibility on where to locate in a convoy. If there is a company or platoon size unit that is traveling in a convoy, then they need to have some means of maintaining connectivity to the POP-V in order to be connected with all other units associated with that POP-V. INMARSAT is the first recommendation due to its strength of the on-board satellite terminal being able to track the airborne satellite while in motion.

The use of aerial relays for CoNDOR can greatly increase the ability to communicate from units to the POP-V and from the POP-V to MSCs. This could be an alternative to relying on LOS radios or satellite communications. Two technologies examined in this thesis are recommended for use in the aerial relay platform, and they are 802.11b over SecNet-11 and OFDM.

Bulk encryption was utilized at General Dynamics and Raytheon. The KG-235 In-Line Network Encryptor proved compatible with FSO, Microwave, and OFDM, and it could definitely work with the other technologies. Detailed analysis needs to be done on how to configure the encryptor appropriately for maximized throughput and where to place the KG-235 into the local area network.

In conclusion, the authors introduced different technologies that offered more flexibility, mobility, and capability for communications on the tactical battlefield. Throughout this research, the focus revolved around testing equipment and network configurations in an IP network in order to demonstrate a tactical wireless edge. Special consideration was given to wireless issues for the UOC, CAC2S, and CoNDOR programs, which could improve line-of-sight, beyond line-of-sight, and over-the-horizon communications for each of them. These new technologies will transform communications in the United States Marine Corps for the 21st century.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. DISCUSSION OF THE PROBLEM

The purpose of this research was to introduce a Transformational Communications Architecture for the U.S. Marine Corps' Unit Operations Center (UOC); Common Aviation Command and Control System (CAC2S); and Command and Control On-the-Move Network, Digital Over-the-Horizon Relay (CoNDOR).

The following three questions address the main issues being examined in this thesis:

1. Can transformational communications technologies alter the intra-nodal communication links in UOC and CAC2S into a more capable and robust signal?
2. Can transformational communications technologies provide more effective inter-nodal communications links between UOC and CAC2S nodes than current legacy equipment?
3. Can transformational communications technologies be utilized in the CoNDOR scenario?

The ultimate goal of this research will be to introduce different technologies that offer more flexibility, mobility, and capability at the tactical level than what current legacy equipment provides. These new technologies could provide the Marine Corps with a tactical wireless edge.

A statement made by Major General Stalder, United States Marine Corps, Deputy Commanding General for I Marine Expeditionary Force (MEF) before the House Armed Services Committee on October 21, 2003 states the following about Operation Iraqi Freedom (OIF):

> In order to support the C2 systems, the MEF and its major subordinate commands incorporated several recently fielded communication technologies. Among these were the Secure Mobile Anti-Jam Reliable Tactical-Terminal (SMART-T), the Tactical Data Network (TDN) gateway, the Digital Technical Control (DTC) facility, and the Deployable KU Earth Terminal (DKET). Overall, these new technologies were a

great success story and contributed significantly to the MEF and Major Subordinate Command (MSC) Commanders' ability to command and control forces in combat.[1]

There have been numerous advances in satellite communications for the MSCs, but this thesis research will dig deeper into the tactical problem within the MSCs. Several units and agencies on the battlefield are still without similar types of communication means and lack the technology to effectively communicate in the new information age.

1. Marine Corps Technology Problem

The Marine Corps is developing new command and control systems such as UOC and CAC2S, and new concepts for Marine Expeditionary Forces to bridge the gap between Major Subordinate Commands (MSC) and their subordinate units, such as CoNDOR. If the Marine Corps continues to rely on legacy communications for these programs, the technology gap will widen even further than what already exists. New technologies, such as the ones researched in this thesis, need to be seriously considered to keep the warfighter one step ahead of the enemy. The authors will look at UOC, CAC2S, and CoNDOR and how to improve line-of-sight (LOS), beyond line-of-sight (BLOS), and over-the-horizon (OTH) communications in intra-nodal and inter-nodal environments.

For a command and control system setup in the Marine Aviation Command and Control System (MACCS), the Marine Corps currently uses fiber optic cable to connect different sites in the intra-nodal scenario. For example, from Combat Operation Center (COC) to communications site, a heavy-duty fiber optic cable is run from one vehicle to another. If the wire is not buried, it becomes vulnerable to elements such as vehicles running over it or the enemy slashing the wire to sabotage the communications capabilities. This creates a significant single point of failure if multiple cables are not run between the sites. For the Ground Combat Element (GCE), large amounts of cable (fiber and/or multi-pair) and/or single pair field wire are currently used to remotely connect the

[1] Major General Stalder, USMC, Brief to House Armed Services Committee, Subcommittee on Terrorism, Unconventional Threats and Capabilities, 21 October 2003.

radios and other communications assets from COC to antenna hill. Thus, the same vulnerabilities exist for the GCE as the MACCS agencies.

Next, for inter-nodal data communications the MACCS relies upon the A/N MRC-142 and the A/N TRC-170, while the ground units rely heavily on the MRC-142. The characteristics of the MRC-142 (Table 3) and the TRC-170 (Table 4) can be found below.

Frequency range	1,350- 1,850 MHz
Bandwidth	100 (125 optional) kHz
Channel rate	144, 288, and 576 kbps
Output power	Low: 300mW (25dBm) High: 3 W (35 dbm)
Frequency Stability	10 ppm
Orderwire channel	Analog: 300- 3,400 Hz Digital: 16 kbps

Table 3. AN/MRC-142 CHARACTERISTICS[2]

The AN/MRC-142 is also generally employed at or above the regimental level. It serves as a flexible, reliable voice and data link in the USMC digital switched backbone system. The AN/MRC-142 has a range of 35 miles, operates at data rates up to 576 Kbps, and will support a maximum of 36 voice channels. The AN/MRC-142's enhanced bandwidth management and data throughput capabilities will enable other critical systems such as the Tactical Data Network (TDN) and the Advanced Field Artillery Tactical Data System (AFATDS) to be fully integrated into Marine Air-Ground Task Force (MAGTF) operations ashore.[3]

Frequency Range	4.4- 5.0 GHz
Bandwidth	3.5 or 7.0 MHz
Transmitter power	1 kW
Diversity	Dual
Data Rates	Up to 4,608 kbps
Channel capacity (at 32kbps)	Up to 144 (includes overhead)

Table 4. A/N TRC-170 CHARACTERISTICS[4]

[2] http://www.fas.org/man/dod-101/usmc/docs/mef99/part-2.pdf (April 2004).

[3] http://www.marcorsyscom.usmc.mil/sites/pmcomm/mrc142.asp (April 2004).

[4] http://www.fas.org/man/dod-101/usmc/docs/mef99/part-2.pdf (April 2004).

The AN/TRC-170 is a transportable, self-enclosed multi-channel tropo-scatter terminal capable of transmitting and receiving digital data over varying distances (up to 100 miles). The MAGTF headquarters and Aviation Combat Element (ACE) will normally use it.[5]

From the tables, the data rates shown are relatively low for the MRC-142 and somewhat sufficient for the TRC-170 compared to what will be needed in the future. These two systems are fairly large and require their own generators for power. The technologies examined in this thesis will definitely complement or provide more refined options than the MRC-142 and TRC-170.

In the CoNDOR setup, the Marine Corps relies on its current inventory of radios to provide data connectivity down to the company level and below, such as the Portable Radio Component (PRC)-104, PRC-119, Mobile Radio Component (MRC)-138, MRC-145 and Enhanced Position Location Reporting System (EPLRS). These are all strictly LOS radios that provide between 2.4 - 56 Kbps of data throughput. All of these radios are eventually going to be phased out by the Joint Tactical Radio System (JTRS) in 2008 and beyond. JTRS is being designed to provide a flexible new approach to meet diverse warfighter communications needs through software programmable radio technology. There will be a significant increase in data throughput up to approximately 2 Mbps, and JTRS will provide reliable multi-channel voice, data, imagery, and video communications. As one can see, the process of getting more throughput to the battlefield is going to take some time with JTRS. Even when JTRS is fully fielded, the technologies evaluated in this thesis could complement the abilities of JTRS in the CoNDOR architecture.

The authors will look at UOC, CAC2S, and CoNDOR, and how to improve LOS and BLOS communications in intra-nodal and inter-nodal environments throughout the thesis. The problem statements for UOC, CAC2S, and CoNDOR below will help further explain the reasons for conducting this research.

[5] http://www.marcorsyscom.usmc.mil/sites/pmcomm/trc170.asp (April 2004).

2. Unit Operations Center (UOC)

The UOC is a modular, scalable and mobile Command and Control System built to facilitate faster and more accurate decision making by Marine operational forces. It is currently going through operational testing with several fleet units.

Battalion and Regiment level UOC use the same component. Regiment level UOC has a requirement to support a Coalition LAN and Video Teleconference (VTC) capability, which is not required for Battalion level. Also, the Regiment must support 15 operators vice eight in the Battalion, and have two Visual Display Systems. To provide the additional power, tents, heating, and cooling, an additional Generator, Environmental Control Unit, and Tent (GET) trailer is required at Regiment. See Figure 1 for more detail of the setup.[6]

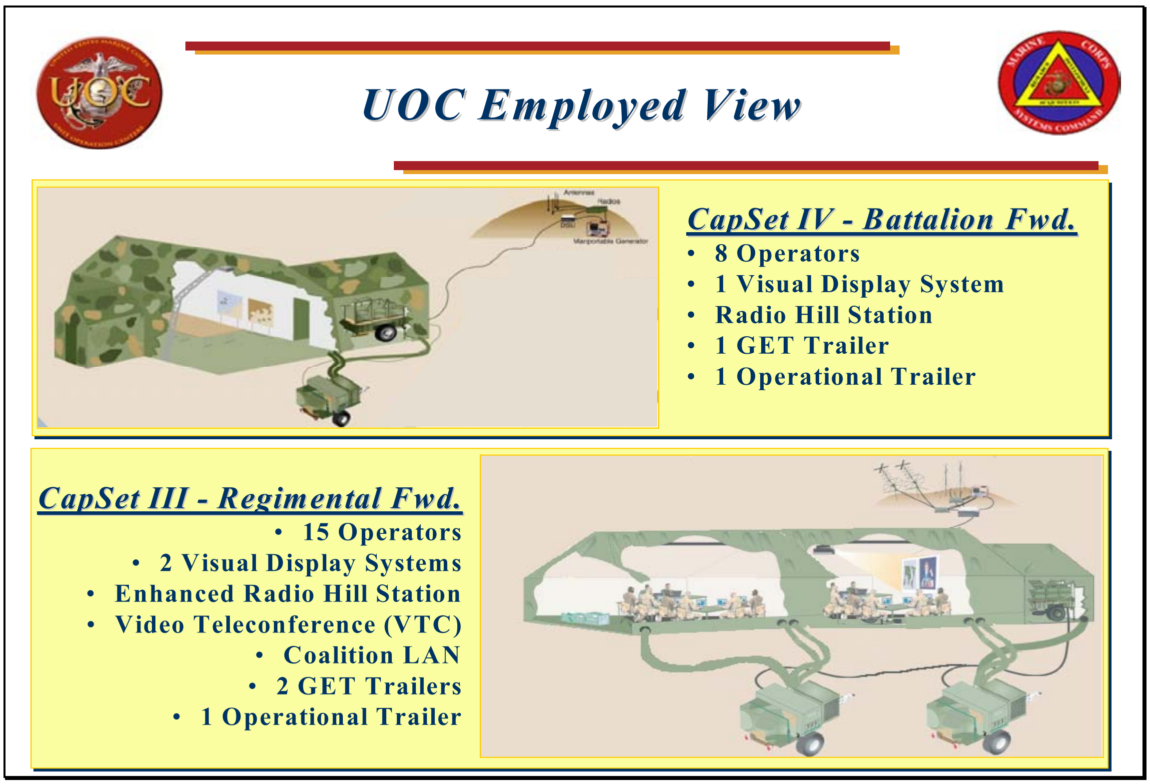

Figure 1. UOC CONFIGURATION FOR INTRA-NODAL SETUP[7]

The node-to-node communication between UOCs resembles the current COC to COC connectivity. Depending on the level of command, battalion and lower still rely on

[6] General Dynamics Decision Systems, "UOC Summary Brief", 2003.

[7] General Dynamics Decision Systems, "UOC Summary Brief", 2003.

LOS radios and UHF Satcom, while regiment and above use the MRC-142 and satellite based communications means. The current Marine Corps plan is to connect the COC and antenna hill via cables and wires.

The Marine Corps understands the vulnerabilities of relying on LOS radios and MRC-142 for data and voice connectivity. During OIF the Marine Corps regiments and divisions relied on satellite communications to maintain connectivity. One of these satellite systems was the Secure, Mobile, Anti-Jam, Reliable Tactical Terminal (SMART-T). SMART-T is a MILSTAR satellite-compatible communications terminal mounted on a High Mobility Multi-Purpose Wheeled Vehicle (HMMWV). It allows long-haul tactical communications for Digital Transmission Groups (DTG), Digital Subscriber Voice Terminal (DSVT), and individual encrypted subscribers, at data rates ranging from 75 bps to 1.544 Mbps.[8]

Even though some efforts have been made to address BLOS issues with node-to-node communications, there are several other wireless options available that will be brought out in this research. Based on visits by the authors over the past few months with the UOC offices at General Dynamics and Marine Corps Systems Command (MCSC), intra-nodal communications via wireless technologies are not included in the requirements for the system and are apparently not being looked at seriously.

3. Common Aviation Command and Control System (CAC2S)

The current MACCS functions with a Tactical Air Command Center (TACC), Direct Air Support Center (DASC), Tactical Air Operations Center (TAOC), Air Traffic Control (ATC), and Low Altitude Air Defense (LAAD) command and control centers. CAC2S will replace these legacy systems in three incremental builds, and it will provide common hardware and software to all users in the MACCS. CAC2S will be scalable, so it can be configured for air, ground, and afloat operations.[9]

The MACCS agencies are dispersed throughout the battlefield with locations and distances being very unpredictable. So, the current structure uses a combination of MRC-142 and TRC-170 systems. The MRC-142 is strictly LOS and the TRC-170 can

[8] http://www.marcorsyscom.usmc.mil/sites/pmcomm/smart_t.asp (April 2004).

[9] Marine Corps Tactical Systems Support Activity, Program Support Division, "CAC2S Technical Briefing", 13 February 2002.

extend out to distances of 100 miles due to the tropo scatter functionality of the system. Since there are not enough TRC-170s for each node located throughout the battlefield, MRC-142s are employed with retransmission sites set up on top of hills or mountains when LOS cannot be attained. Figure 2 shows how CAC2S is planning to communicate when the systems are fielded in 2007 and beyond. This is identical to how the current MACCS communicates. Thus, one can see the dangers of not upgrading the communication capabilities with the new system.

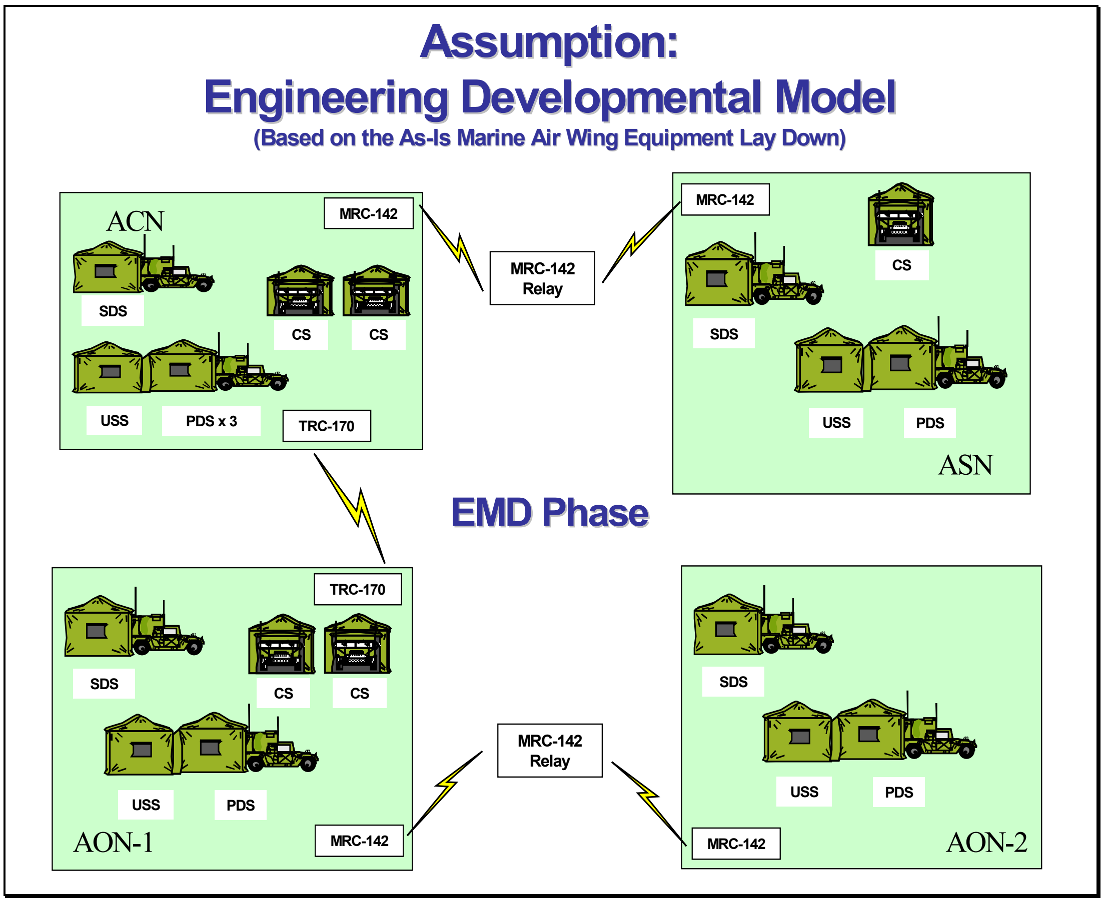

Figure 2. CAC2S FOR INTER-NODAL AND INTRA-NODAL COMMUNICATIONS

The present plan between Raytheon (organization assisting the Marine Corps develop CAC2S) and Marine Corps Systems Command is to continue to connect the intra-nodal sites within each node by fiber optic cable. For example at the Air Support Node (ASN) node, the Processing and Display Subsystem (PDS) will be connected to the Communications Subsystem (CS) and the Sensor Data Subsystem (SDS) via a heavy-duty fiber cable. There will also be fiber cable runs between the SDS and CS sites. This setup provides redundancy between all the sites, but it still is vulnerable and relies upon the cumbersome and expensive tasks of laying and burying wire.

4. Command and Control On-the-Move Network, Digital Over the Horizon Relay (CoNDOR)

The CoNDOR Capability Set is an Architectural Approach designed to bridge battlefield Command and Control over variable distance, either LOS or over-the-horizon (OTH). Figure 3 shows a CONDOR point-of-presence (POP) vehicle. It will facilitate communication with High Frequency (HF), Very High Frequency (VHF), Ultra High Frequency (UHF), UHF Satcom, and EPLRS radios. As JTRS evolves and is fielded, CoNDOR will be able to integrate these radios as well. Several technologies are being evaluated for CoNDOR's satellite access to higher headquarters while it is stationary and on-the-move.

Figure 3. CoNDOR POP VEHICLE[10]

One problem that is inherent to the CoNDOR setup is that legacy LOS radios and eventually JTRS are being relied upon to provide data connectivity. These are all limited in throughput capabilities, for example legacy radios are less than 56 Kbps and JTRS is below 2 Mbps of throughput. The satellite communications system currently being looked at to connect the POP vehicle to higher headquarters is also limited in throughput (less than 1 Mbps). Several technologies evaluated in this research are viable options to

[10] https://www.quickplace.marcorsyscom.usmc.mil/CoNDOR (April 2004).

connect the CoNDOR POP vehicle at the battalion level down to the lower levels as well to connect the battalion POP vehicle to higher headquarters in a BLOS or OTH situation.

In order to have a better understanding of the problem statements for UOC, CAC2S, and CoNDOR, detailed background information is given on each program below. The authors were able to visit each of the respective program offices at MCSC. In addition, they visited Raytheon's CAC2S and General Dynamics' UOC program offices and Space and Naval Warfare Command (SPAWAR) Charleston, where several personnel are working with MCSC on UOC, CAC2S, and CoNDOR. This was all done for first hand knowledge of the programs and their progress.

B. BACKGROUND INFORMATION

The information discussed in the following paragraphs is designed to give the reader a general understanding of the programs involved in this thesis. By no means are the authors speaking on behalf of the program offices mentioned below.

1. UOC

a. Current

The UOC is designed to provide Marine operational forces with command and control capabilities whenever and wherever Marines operate or fight.[11] The UOC is to provide the Ground Combat Element (GCE) commander with the necessary hardware, software, equipment, and facilities to effectively command, coordinate, and control MAGTF air in joint/multi-national operations. The UOC will be mobile, expandable, scalable, modular, command and control interoperable system in a HMMWV, C-130, or ship. The UOC will first be fielded to GCE, followed by the Command Element (CE), and the Combat Service Support Element (CSSE). The UOC facilitates command and control for the above elements. Figure 4 depicts a Marine in the UOC. Lieutenant Colonel Tolbert from MCSC best captures the purpose of the UOC:

> The UOC program seeks to maximize the commander's decision making superiority by providing digital tools and a fully integrated Combat Operations Center (COC) that uses common hardware

[11] UOC summary power point brief; General Dynamics

across the Marine Corps. This will result in increasing unit efficiency and combat effectiveness.[12]

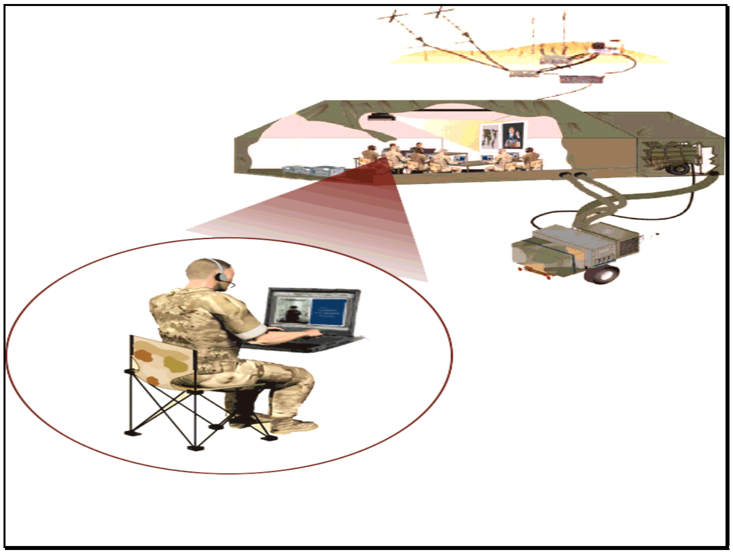

Figure 4. MARINE IN THE UOC

According to Headquarters Marine Corps, "The COC will provide the servers to host applications required by the commander. These applications include the Global Command and Control System (GCCS), Tactical Combat Operations (TCO), Intelligence Analysis System (IAS), Advanced Field Artillery Tactical Data Systems (AFATDS), and Theater Battle Management Core System (TBMCS). The COC will connect to the Tactical Data Network for Digital Message System (DMS) services."[13]

The operational impact the UOC will have is that the commander and the commander's staff will be able to receive a Common Tactical Picture (CTP) via data and voice communications. The UOC will have the capability of functioning as a reconfigurable, scalar, mobile, and deployable command and control system.[14] This capability will have a significant impact in Marine warfare by providing the foundation to facilitate command and control on the battlefield.

[12] http://www.gdds.com/uoc/uoc_digitalcombat.html; **LtCol Donald D. Tolbert, Jr;** Unit Operations Center: The Digital Combat Operations Center of the Future, Reprinted from **Marine Corps Gazette**, January 2003.

[13] http://hqinet001.hqmc.usmc.mil/p&r/concepts/2001/PDF/UOC.pdf

[14] Ibid

b. Future

The UOC is configured in predefined capability sets (CapSets). There are four CapSets: CapSet I is configured to support a Marine Expeditionary Force, CapSet II is configured to support a Division, CapSet III is configured to support a Regiment, and CapSet IV is configured to support a Battalion (Figure 5).[15] The estimated completion date for the initial operational capability is late 2004. In fiscal year 2005, twenty more units will be procured in order to support Operation Iraqi Freedom and technology inserts.[16]

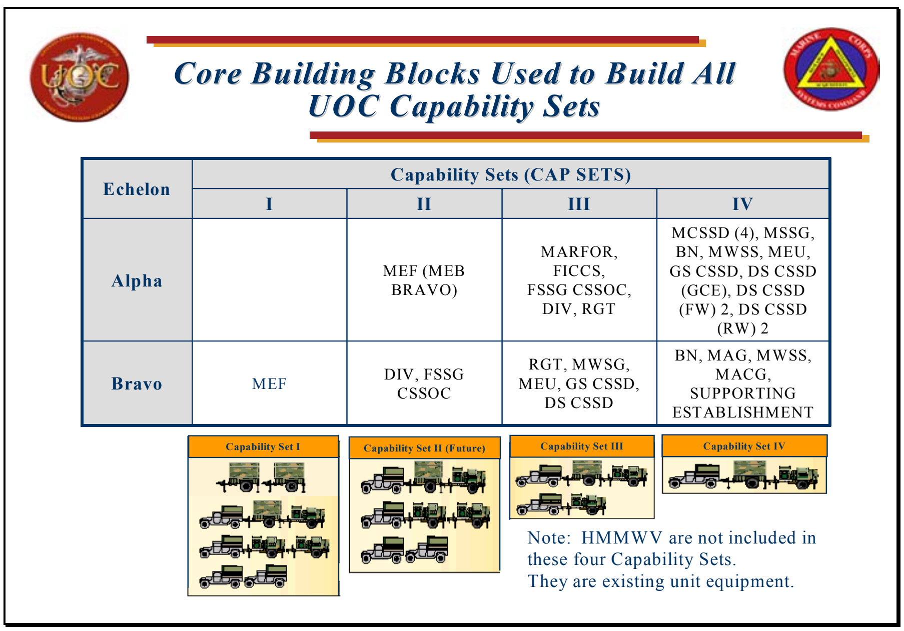

Figure 5. UOC CAPABILITY SETS

The UOC is designed with a T3 design: Tents, Trailers, and Transit Cases (Figure 6). The generator, environmental control unit, and tent are located on the GET (generator, environmental control unit, and tent) trailer.[17]

[15] Detailed UOC power point brief; General Dynamics

[16] Conversation with Kevin Holt, USMC UOC team leader, MCSC

[17] Ibid; General Dynamics power point presentation

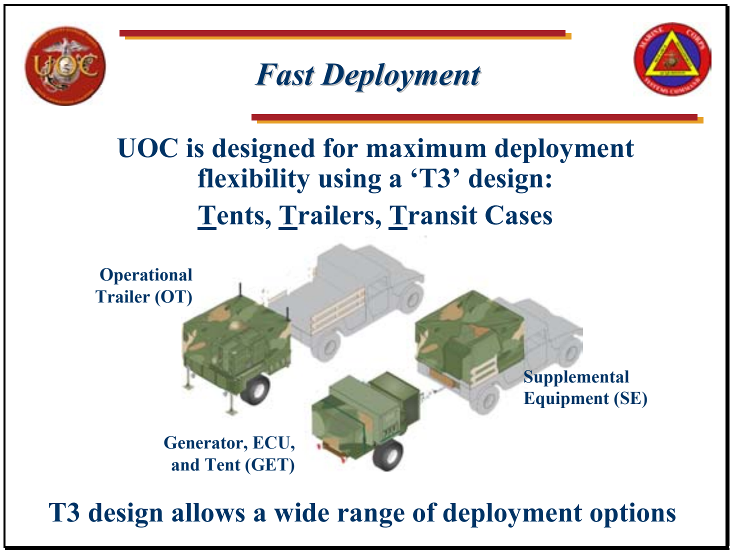

Figure 6. T3 DESIGN

The operational trailer (OT) is the key component in the T3 design. The operational trailer has a rack structure that supports and provides a secure network, a non-secure network, uninterrupted power supply, eight operator workstations, intercom, public address system, and on-the-move capability (via EPLRS, VRC-92, and PSC-5). The transit cases do not need to be removed from the trailer, hence, reducing the setup time. The transit cases are interconnected with cable harnesses that are permanently installed on the rack. All cable connectors are accessible either from the front of the equipment or from the rear with sufficient cable service loops. The supplemental equipment provides a repeatable load plan and the capability of reusable harnesses and straps.

2. CAC2S

a. Current

This program is to provide the Aviation Combat Element (ACE) commander with the necessary hardware, software, equipment, and facilities to effectively command, coordinate, and control MAGTF air in joint/multi-national operations. CAC2S is a mobile, expandable, scalable, modular, full command and control interoperable system in a Highly Mobility Multi-Purpose Wheeled Vehicle (HMMWV), C-130 aircraft, or ship. CAC2S provides a common operational picture for air operations, weapons control, communications, sensors, and other displays. The key feature of the program is that it functionally replaces dissimilar stovepipe systems currently utilized by the Marine Aviation Command and Control System (MACCS). Additional features are that it reduces the footprint and lift, while providing a complete and coordinated modernization effort capable of supporting Expeditionary Maneuver Warfare (EMW).[18] See Figure 7 for illustration.

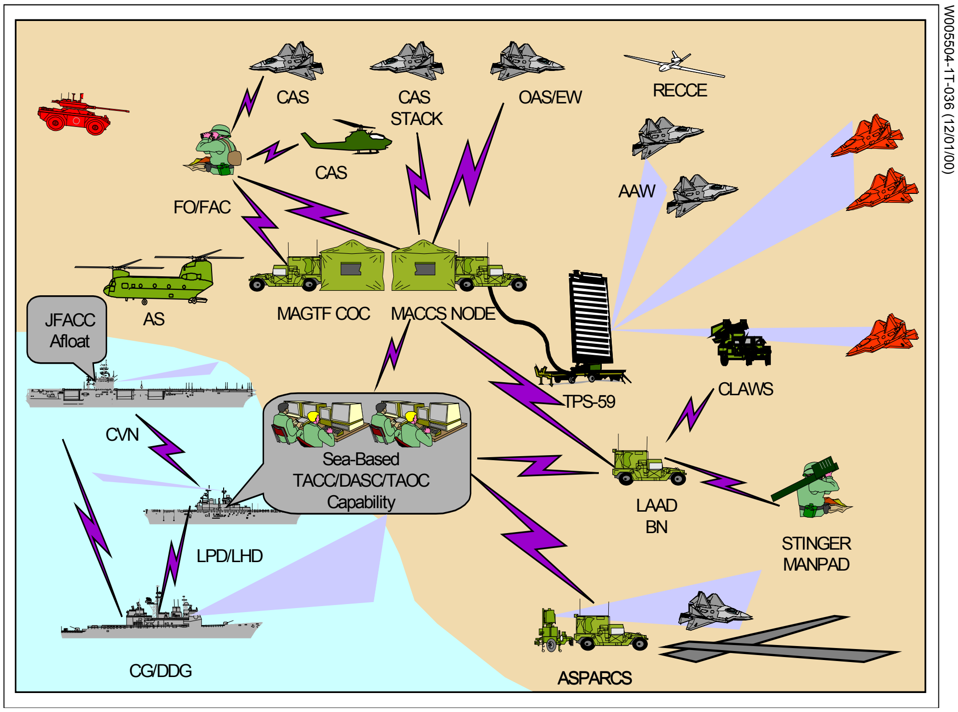

Figure 7. CAC2S OVERVIEW

CAC2S provides the means to revolutionize the equipment base and operational concepts of the MACCS to support Operational Maneuver From the Sea (OMFTS). CAC2S will provide the MAGTF commander with the mission critical support system required to integrate aviation and ground combat operations in support of the Marine Corps' operational objective. CAC2S will provide the ACE commander and battle-staff with the capability to communicate with higher, adjacent, and subordinate units, as well as the ability (through subordinate MACCS agencies) to exercise real-time positive control, coordination, and direction of MAGFT and joint air assets. CAC2S components will operate from aerial platforms, amphibious shipping and from C2

[18] CAC2S SFR Brief: October 21-22, 2003

agencies ashore. In other words, CAC2S will operate on land, at sea, or from the air to support Marine Corps war fighting concepts for the 21st Century. [19]

CAC2S provides an operational impact in conjunction with MACCS organic sensors and weapon systems in order to support the tenets of Expeditionary Maneuver Warfare and fosters joint interoperability with Department of Defense's command and control systems. CAC2S will replace legacy C2 systems in the following Marine aviation C2 elements: Tactical Air Operations Center (TAOC), Tactical Air Command Center (TACC), Direct Air Support Center (DASC), Marine Air Traffic Control Detachment (MATCD), and Low Altitude Air Defense Battalion (LAAD BN).[20]

b. Future

CAC2S will be comprised of modules and subsystems. Hardware components for CAC2S will be modular and man-portable. According to Marine Corps Tactical Systems Support Activity (MCTSSA):

> The CAC2S modules are scalable to meet mission requirements. The modules will be assembled to create an operational node. The core software of the CAC2S will include all of the functions common to all current MACCS agencies, including the ACE requirement for aviation C2 planning. Mission unique functions will be configurable and selectable from every workstation. The CAC2S will interface with, but not replace, radios, air defense weapons, and sensors organic to the MACCS.[21]

The Raytheon estimated completion date for the initial operational capability is February 2007. The program status, according to the CAC2S brief, is as follows:

> The CAC2S and UOC programs are being developed in parallel to eventually achieve a common MAGTF Operations Center solution. CAC2S is being developed in an evolutionary acquisition strategy in four increments. Increment I will replace the functionality of the TAOC and will baseline the core information fusion and management function common to all increments and eventually all MAGTF Operation Centers. Increment II will replace TACC and DASC nodes. Increment III will achieve integration between

[19] Power point brief; MCTSSA CAC2S BRIEF 13 FEB 02

[20] http://hqinet001.hqmc.usmc.mil/p&r/concepts/2000/PDFs/Chapter4/ch4_p1_11_CAC2S.pdf

[21] http://www.mctssa.usmc.mil/PSD/CAC2S%20fact%20sheet.pdf

> CAC2S and the Air Surveillance and Precision Approach Radar Control System (ASPARCS) for Air Traffic Control functionality. Increment IV is the transition to the complete MAGTF Operation Center functionality. CAC2S is an ACAT III program currently in the definition and risk reduction development phase.[22]

MCTSSA captures the different increments in Figure 8.

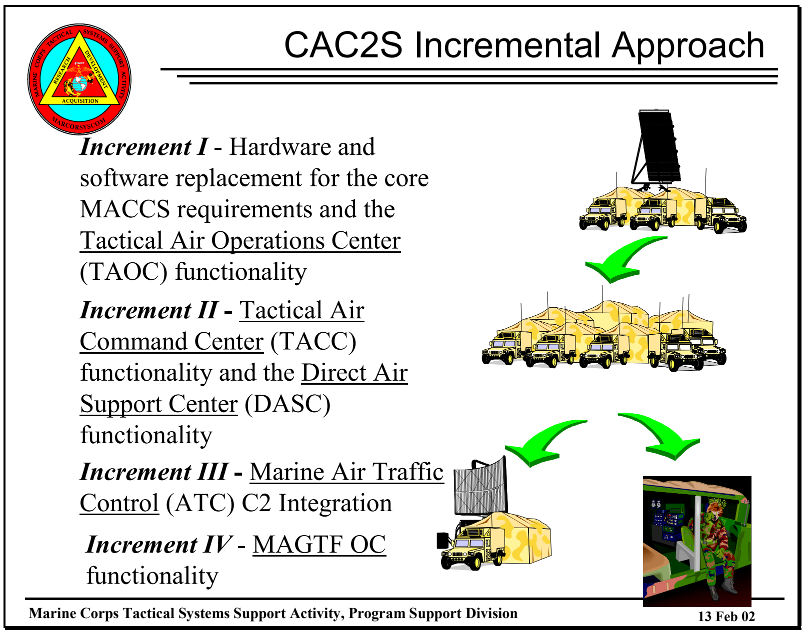

Figure 8. CAC2S INCREMENTAL APPROACH

3. CONDOR

a. Current

According to MCSC, "CoNDOR capability set is a program of record that provides the ability to link dispersed OTH and/or BLOS operators."[23]

In order to better understand CoNDOR, the reader needs to understand how Marine Corps communications works. Marine Expeditionary Force (MEF) and MSCs like the Division, Wing, and Force Service Support Group Headquarters have historically had reliable connectivity. The MEF and MSCs have been connected via large satellite networks. Telephone connectivity, a military version of public switched telephone network, is then built into the satellite networks. Data connectivity for

---

[22] www.hqinet001.hqmc.usmc.mil/p&r/concepts/2002/PDF/CH3_Part3/ch3%20part%203%20CAC2S.pdf

[23] Lieutenant Colonel J.D. Wilson, "Draft CoNDOR C4ISP", MCSC, March 2004

classified and unclassified networks is provided via a Tactical Data Network, which usually uses the satellite links. The major limitations for MEF and MSCs are the lack of satellite throughput available to support the high bandwidth demand and the loss of communications when the MSC commander displaces to a new location.[24]

The infrastructure for maneuvering commands like Companies, Batteries, or mobile Combat Service Support Detachments, is limited to LOS radios and small amounts of bandwidth availability. These limited communications are means by which the maneuvering commands communicate to their Battalions, Regiments, or higher headquarters. Data travels across the battlefield via EPLRS, or through a point-to-point system using modems such as ViaSat. Once the information reaches the MSC level, it is passed along the MSC communication links. The major limitations have been the limited bandwidth provided by the tactical radios and the lack of an OTH capability. Through the efforts of the Office of Naval Research (ONR) and MCTSSA connectivity for the maneuver forces from the ship to the objective area has been provided by a communications bridge via the CoNDOR gateway (Figure 9). The CoNDOR gateway uses EPLRS to establish the communications bridge, but there are units that do not have EPLRS. For these units a Point of Presence Vehicle (POP-V) provides connectivity to the MSC. The data is very limited however, due to the throughput of the tactical radio, as described in the problem statement above.

[24] Lieutenant Colonel J.D. Wilson, "CoNDOR Overview", MCSC, power point presentation March 2004

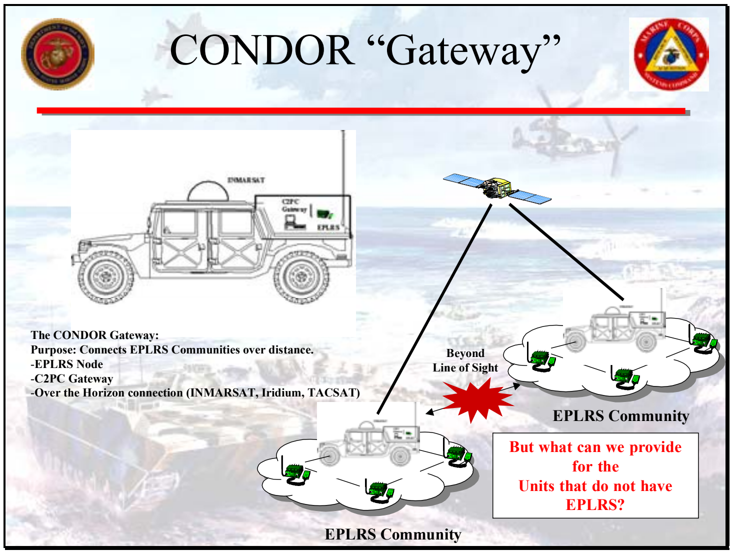

Figure 9. CONDOR GATEWAY

b. Future

The CoNDOR gateway consists of an EPLRS node, a Command and Control Personal Computer (C2PC) gateway, and OTH connectivity (INMARSAT, Iridium, or TACSAT). In a PoP-V the gateway will consist of tactical radios (SINCGARS, Have Quick II, TACSAT DAMA, HF, HF ALE, EPLRS), C2PC gateway, and OTH connectivity (Figure 10).

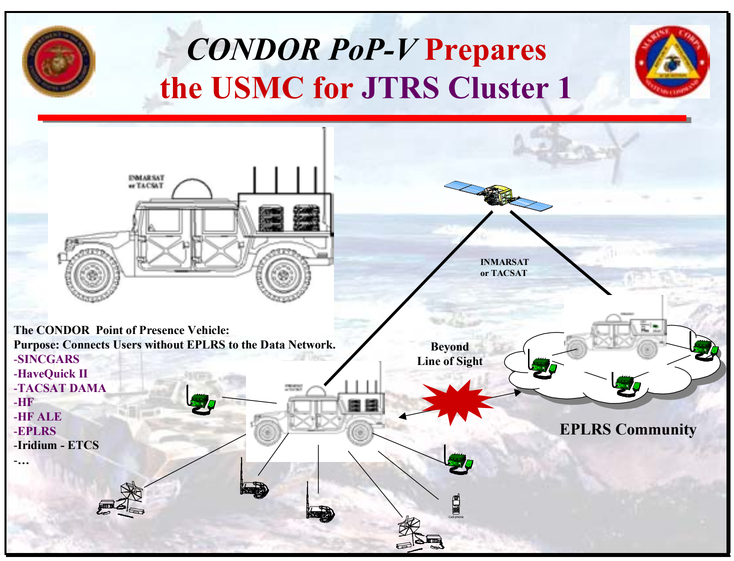

Figure 10. CONDOR POP-V

The CoNDOR PoP-V will provide the capability of extending the network via tactical radios. Additionally, the CoNDOR PoP-V will give insight on how to configure the architecture for the Joint Tactical Radio System (Figure 11).

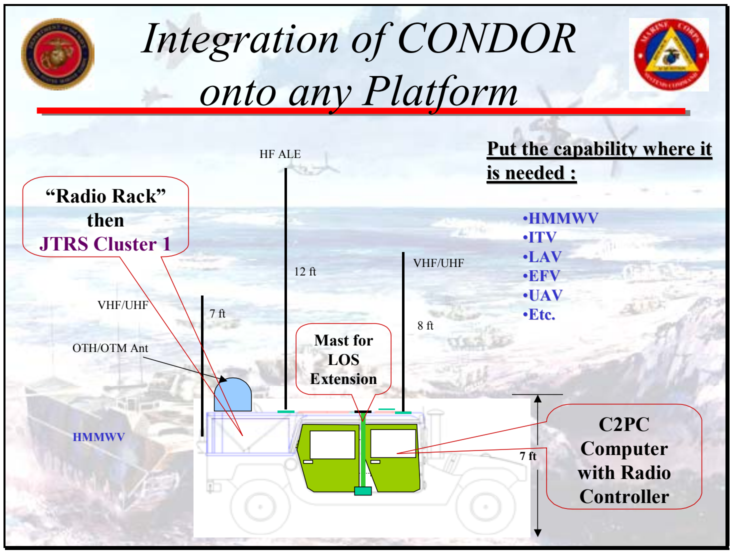

Figure 11. USMC JTRS CONDOR POP-V

Integration capabilities for CoNDOR are being conducted in a universal communications interface module (UCIM). The UCIM is a modular component set that will configure vehicular power to communications systems; load and configure all radios (legacy and JTRS); load and tune the antennas; provide a keyboard, video, and mouse functionality from any seat; provide a central processing unit to host applications (C2PC gateway, SPEED, etc.); and create an enclave, coupling C2 systems with radios. Other capabilities are being developed in a CoNDOR JUMP C2. In the CoNDOR JUMP C2, the commander will have continuous connectivity even when the unit displaces from one location to another. The continuous connectivity increases situational awareness and enhances the commanders' command and control capabilities (Figure 12).

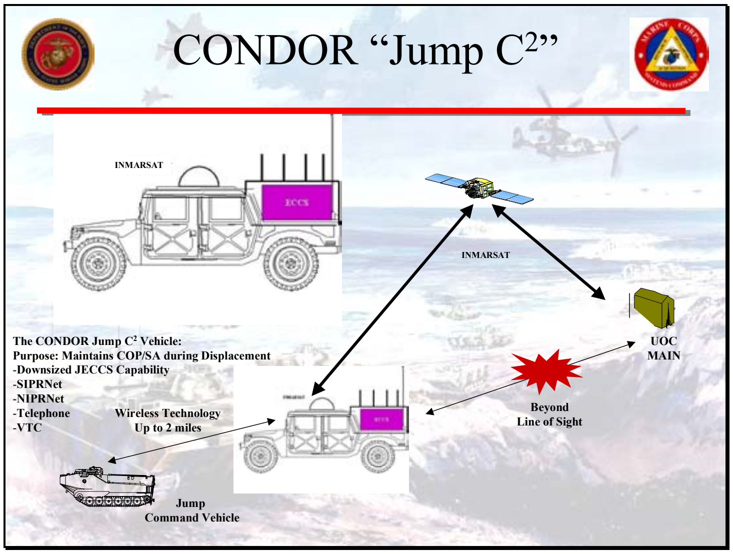

Figure 12. CONDOR JUMP C2

This section discussed the background of the programs that are addressed in this thesis. The following sections will further explain the statement of the problem and the methodology used to approach it.

THIS PAGE INTENTIONALLY LEFT BLANK

II. RESEARCH METHOLOGY AND FIELD TESTS

Multiple technologies were evaluated for potential use in three Marine Corps programs: UOC, CAC2S, and CONDOR. The authors used a “building block” approach to become familiar with the research topic and available technologies in the commercial sector.

First, the authors visited Marine Corps Systems Command, Space and Naval Warfare Systems Command - Charleston, Office of Naval Research, Marine Corps Warfighting Laboratory, and Marine Corps Tactical Systems Support Activity to become familiar with the Marine Corps programs and current research being conducted. In addition, the authors visited private company laboratories to observe applicable technologies working in an operating environment. Finally, the authors visited the UOC program office at General Dynamics Decision Systems (GDDS) in Scottsdale, AZ and the CAC2S program office at Raytheon in San Diego, CA to become familiar with the research being done by government contractors to exploit the wireless communications industry.

Following these visits, four field-testing events were planned over a five-month period starting in November and ending in March. The field events began with a “backyard exercise” in the Monterey, CA area to become familiar with various network configurations and some of the technologies being evaluated. Next, in January, the authors traveled down to GDDS to work with the UOC team and demonstrate the different technologies to them. The authors then went to Raytheon in February in order for the CAC2S team to see what technologies were available for possible intra-nodal and inter-nodal communications. Finally, in March the authors traveled to Camp Roberts, CA to conduct a realistic field-testing event that simulated a CONDOR scenario. In order to facilitate the research the authors utilized the Naval Postgraduate School’s Mobile Research Facility (MRF). This is a 33-foot Recreational Vehicle that was converted into a mobile Network Operations Center. Connectivity was tested from this platform in order to simulate Command Center to Antenna Hill and CAC2S node to

CAC2S node links. The data obtained from these testing events was used by the authors to evaluate various commercial technologies for potential use in Marine Corps operations.

Marketing and technical literature from all the companies were also reviewed to include system/subsystem specifications, test evaluations, and engineer assessments.

Finally, the visits to program offices and private companies, was combined with the testing and document research, to formulate recommendations for future UOC, CAC2S, and CONDOR communications architectures.

A. FIELD TEST #1 (FORT ORD AND BIG SUR, CA)

The purpose of the first experiment was to become familiar with Free Space Optics (FSO) Equipment and 802.11 link equipment in order to establish a baseline for follow-on testing for transformational wireless communications technologies for UOC, CAC2S, and CoNDOR. The methodology used was to establish two Local Area Networks (LANs), one at a fixed site (Figure 13) and one at the MRF (also known as Nemesis). These two LANs were then linked using two different FSO systems, (fSONA 17 & 18 November and Lightpointe 20 & 21 November). 802.11 wireless technology was also used during both test periods. These tests are described in the sections that follow.

Figure 13. FIXED SITE AT BIG SUR

Some of the anticipated results were to be able to develop a more thorough understanding of the limitations, set up, throughput, and mobility of FSO and establish a methodology for future experiments. This was a "kick the tire" experiment where the primary focus was to establish a wireless link between two sites and gather information such as power, special connectors, and logistical requirements in order to conduct an experiment.

1. Line-of-Sight (LOS)

a. fSONA

fSONA specializes in Free Space Optics communications. The company is based in British Columbia, Canada. This FSO company was eager to assist during this testing event, as well as each of the others. Their team consisted of the following people: Mike Corcoran, Vice President Sales; Grant Merkley, Inside Sales; Pablo Bandera, Product Manager; and Sean Dante, Field Technician. The Naval Postgraduate School

(NPS) students primarily involved were Captain Gilbert Garcia (USMC), Captain David Joseforsky (USMC), Lieutenant Albert Seeman (USN), and Lieutenant Jesus (Manny) Cordero (USN).

Testing was conducted on November 17-18, 2003 for fSONA. On 17 November, a test was conducted at a distance of 580 meters in an urban environment at Fort Ord, California, and on 18 November testing was conducted at Big Sur, California, in order to establish a longer link (850 m) than the one used at Fort Ord. The equipment used was the SONAbeam 155-M model (Figure 14), which delivered an OC-3 data rate (155Mbps), but during the experiment the link was running at Fast Ethernet speeds (100 Mbps). This product provides a full duplex transmission at the physical layer with four independent lasers, drivers, coolers, and cooler controllers. It comes with a cast aluminum housing, yoke, and mount. The fiber optic interface is a Single-Mode or Multi-Mode fiber, SC terminated. The SONAbeam 155-M system was designed to mount to any vertical pole of diameter 2.5" to 4.5". The FSO transceivers were set up on a ten-foot steel pole with three legs to stabilize the pole. Each leg and the pole weighed roughly fifty pounds. This allowed the FSO link to be very stable. These pole mounts were not fSONA's, and were actually bigger than they really needed to be. Other means are being explored by fSONA to find a mount that is more field expedient and suitable for the Marine Corps.

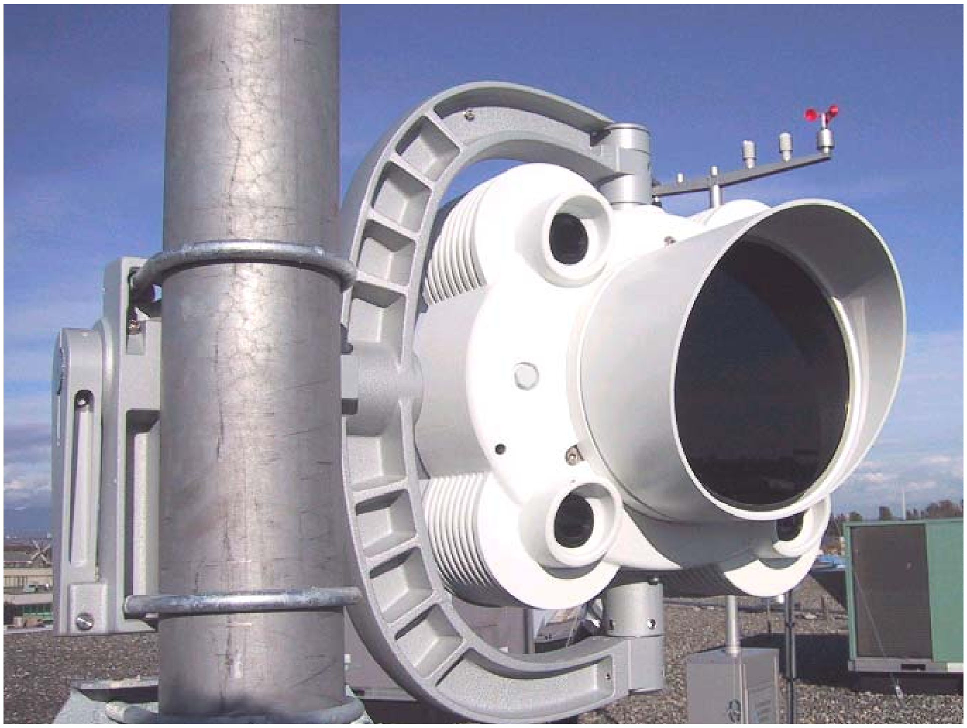

Figure 14. SONABEAM 155M MODEL

The weather conditions for this testing were ideal, with clear skies and calm winds. Figure 15 depicts an overview of the LAN configuration showing the physical layout of the testing equipment and the IP addresses for each piece of gear in the network.

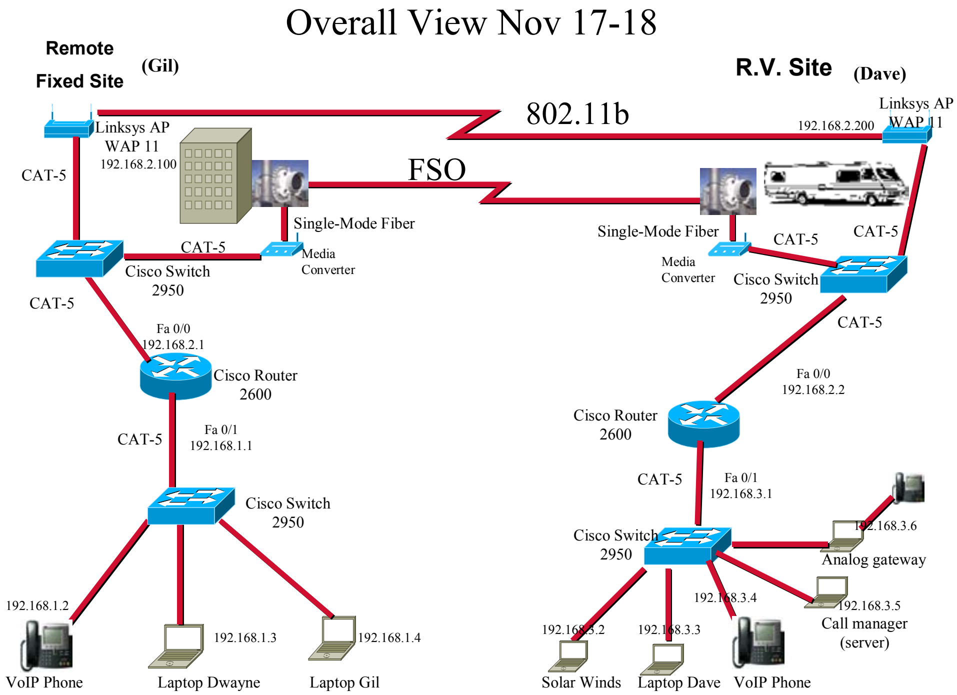

Figure 15. OVERVIEW DIAGRAM fSONA EXPERIMENT

fSONA representatives set up fSONA's FSO equipment. On 17 November, they demonstrated the setup of the equipment and also showed the NPS team how to align the link. The total set up time was one hour including a detailed explanation to the users on how to set up the gear properly. Seasoned field technicians from fSONA, on previous occasions, have set up the gear and had it operational within 30 to 45 minutes.

Each day, media converters were placed between the FSO link and the WAN switches because the Cisco 2950 switches being used did not have the appropriate interface to connect directly to the FSO link. Single-mode fiber was interfaced from the FSO link to the media converter. From the media converter, RJ-45 cable was interfaced to the Cisco 2950 Switch.

On 18 November, an 850 meter link was established at Big Sur from the NPS facility (fixed site) to the base of a mountain where Nemesis was located (Figure 13). Captain Gilbert Garcia and Captain David Joseforsky set up the fSONA equipment in order to demonstrate the ease of equipment setup. Captains Garcia and Joseforsky were able to set up and establish the link within 60 to 90 minutes. This included aligning and fine-tuning the lasers. Alignment of the lasers consisted of centering the distant optical head in the cross hairs of a riflescope. Fine-tuning of the lasers was conducted by turning screws on the optical link head. A voltage reading, a measurement corresponding to the received optical power of the terminal of the distant link's sensitivity, was read on a voltmeter. This reading was used to fine-tune the alignment.

The data collected from fSONA's FSO link was limited due to network issues. The initial plan was to establish streaming video between two computers on different networks, and measure the throughput. The authors were unable to stream video between the LANs because of equipment limitations. Next, video sharing was attempted with less than desirable results. As it turned out, only measured transmission between the two networks was during file sharing. Mapping a network drive and connecting to the remote computer on the different network accomplished this task. The table below gives the data collected from fSONA's FSO link (Table 5).

17-Nov-03						
Run No.	**Media**	**Size**	**Time**	**Type**	**Throughput**	**Packet Loss (%)**
1 (Net Meeting)	FSO	7MB	30 sec	1:01	1.2MB	0%
2	FSO	36MB	3 min	1:01	1.2MB	0%
18-Nov-03						
Run No.	**Media**	**Size**	**Time**	**Type**	**Throughput**	**Packet Loss (%)**
1 (File Share)	FSO	6.5MB	30 sec	1:01	35MB	
2	FSO	14/35MB	10s/45s	2:01	6.26MB	files at same time

Table 5. RAW DATA FROM FSONA

b. Lightpointe

Lightpointe is a FSO company based in San Diego, California. The team was top-notch and was very customer-oriented. The members of this organization were Jim McGowen, Director of Sales; Albert Borquez, Senior Network Engineer; and Steve

Hane, VP Business. The NPS students primarily involved were Captain Gilbert Garcia, Captain David Joseforsky, LT Albert Seeman, and LT Jesus (Manny) Cordero (Figure 16).

Figure 16. TEAM LIGHTPOINT AND NPS STUDENTS

Testing with Lightpointe was conducted on November 20-21, 2003. The setup was straightforward and simple. As before, two LANs were established, one at the fixed site and the other at the MRF. The distance between the two sites was 850 meters. The diagram below (Figure 17) gives an overview of how equipment for the experiment was configured.

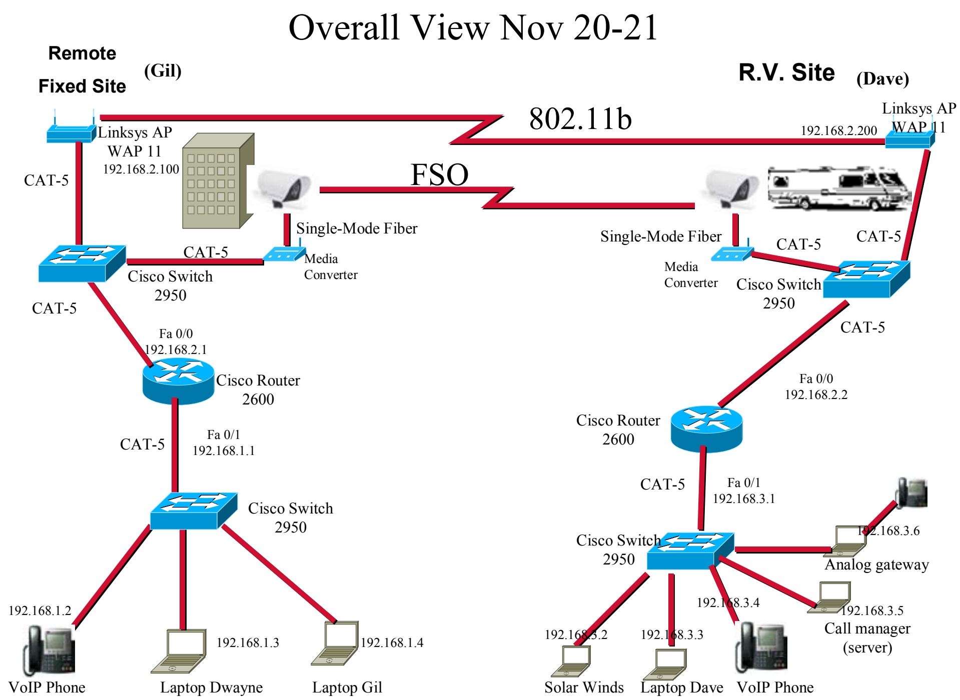

Figure 17. OVERVIEW DIAGRAM LIGHTPOINTE

On 20 November, the primary focus was to see if the outer switch would be able to handle both 802.11b and FSO simultaneously. First, Lightpointe explained to the students how to set up the equipment and demonstrated the ease of equipment setup for the network.

Lightpointe brought their FlightStrata-G Fly Away Kit. The FlightStrata (Figure 18) has a data rate of 1.25 Gbps. It provides full duplex transmission at the physical layer with a flexible distance of 1 meter (can transmit any distance between one meter and 4,800 meters). It features automatic beam tracking and automatic gain control. It has a Multi-mode fiber interface, but a Single-mode fiber interface is available. The FlightStrata took 5 minutes to acquire signal (both ends communicating to each other) and about 20 minutes of fine-tuning (optimizing the signal between the two ends).

Figure 18. LIGHTPOINTE FLIGHTSTRATA MODEL

Albert Borquez, Lightpointe's Senior Network Engineer; LT Manny Cordero, NPS; and Captain Dwayne Lancaster (USMC), NPS, configured the switches and routers. Data was collected to see if the switch was able to handle 802.11b and FSO simultaneously. Files being sent were similar to files that might be used on the battlefield between two units (i.e. data files composed of Word documents, Power Point documents, Excel spreadsheets, PDF documents, and text documents). A 6 Megabyte file was sent and recorded with a throughput of 1 Mbps using SolarWinds (see annex for further explanation of SolarWinds). The following raw data obtained on November 20 shows the throughput results when comparing 802.11b and Lightpointe's FSO (Table 6).

Run No.	Media	Size	Time	From	To	Type	Throughput	Packet Loss (%)
1	FSO	324M	1' 32"	1.3	3.3	1:01	34M	0
2	RF	4M	1' 15"	1.3	3.3	1:01	500K	18
3	FSO	147M	45"	1.3	3.3	1:01	33M	0
4	FSO	147M	41"	3.3	1.3	1:01	42M	0
5	FSO	324M	1'	3.3	1.3	1:01	timed-out	time-out
6	RF	4M	34"	3.3	1.3	1:01	1.3M	21
7	RF	16K	5"	1.3	3.3	1:01	none	20
8	RF	64K	3"	1.3	3.3	1:01	none	19
9	RF	70K	2"	1.3	3.3	1:01	none	18
10	RF	123K	4"	1.3	3.3	1:01	none	17
11	RF	144K	3"	1.3	3.3	1:01	none	16
12	RF	147K		1.3	3.3	1:01		15

Table 6. RAW DATA FROM LIGHTPOINTE FSO AND RF

On 21 November, Captain Garcia and Captain Joseforsky established the link on their own. The initial link setup took approximately 5 minutes and fine-tuning took an additional 30 minutes. This demonstrated how quickly individuals with little training could deploy the system. The focus was on FSO time latencies. The results of the second day of testing are as follows (Table 7):

Run No.	Media	Size	Time	From	To	Type	Throughput	Packet Loss (%)
13	FSO	324M	1' 11"	3.3	1.3	1:01	43M	0
14	FSO	89M	19"	3.3	1.3	1:01	43M	0
15	FSO	89M	17"	1.3	3.3	1:01	46M	0
16	FSO	32M	6"	3.3	1.3	1:01	36M	0
17	FSO	32M	7"	1.3	3.3	1:01	43M	0
18	FSO	26M	4"	3.3	1.3	1:01	31M	0
19	FSO	26M	6"	1.3	3.3	1:01	36M	0
20	FSO	20M	5"	3.3	1.3	1:01	25M	0
21	FSO	20M	4"	1.3	3.3	1:01	14M	0
22	FSO	4M	2"	3.3	1.3	1:01	5.8M	0
23	FSO	4M	2"	1.3	3.3	1:01	5.8M	0
24	FSO	648M	2' 20"		<=	N:N	44M	0

Table 7. RAW DATA FROM LIGHTPOINTE FSO

The final portion of the Lightpointe test was to physically cover different portions of the FSO transceiver lens and annotate the results. The purpose of the test was to determine how much of the optical lens needed to be exposed in order to effectively transfer data between the two LANs. This test was not conducted with fSONA due to time limitations. While transferring a 147 Mb file between two computers on two different LANs, a 25Mbps throughput was produced by covering one of the four transmitting lasers. The entire optical head was then covered until the signal was lost. Once the signal was lost, data stopped transferring and it took 20 seconds to reacquire the signal after the laser heads were uncovered (the 20 second interval is the minimum time Cisco products need in order to determine what is currently connected in the network). When two laser heads were covered, a 45 Mbps throughput was produced across the network. The entire optical head was covered again until the signal was once again lost. At that point, it took 20 seconds to reacquire the signal. When three laser heads were covered, a 45 Mbps throughput was produced across the network. The signal was lost when the entire optical was covered. Once again, the signal stopped transferring data, and it took 20 seconds to reacquire the signal. By walking in front of the laser twice, the signal was lost and it took 30 seconds to reacquire the signal. By passing a lid quickly in front of the laser, the signal was lost. Finally, after passing a water bottle in front of the laser, the signal experienced a 13 percent packet lost. The signal remained acquired throughout the water bottle test.

Conclusions and recommendations from this experiment can be found in the Conclusions and Recommendations portion of this thesis.

c. 802.11b

The Naval Postgraduate Students primarily involved were Captain Gilbert Garcia, Captain David Joseforsky, LT Albert Seeman, and LT Jesus (Manny) Cordero. The time period of this testing experiment was November 17-21, 2003.

The equipment used for this testing was the Linksys Access Point (WAP11). The goal was to test the throughput of 802.11b with yagi and parabolic antennas connecting two Linksys access points. The access points were configured in bridging mode for this portion of the testing. On 17 November, the 802.11b link was set up at 550 meters with yagi antennas. Initial connectivity was established with these antennas in order to connect the two networks. Parabolic antennas were erected next to establish connectivity at 550 meters connecting the two LANs. On 18 November, the same configuration was used at 850 meters in order to share files via NetMeeting. SolarWinds, a product used to measure throughput, determined that NetMeeting had a

1.27 Mbps limit on the amount of maximum throughput. Table 8 below represents the raw data collected for this portion of the experiment.

17-Nov-03						
Run No.	**Media**	**Size**	**Time**	**Type**	**Throughput**	**Packet Loss (%)**
1	Yagi	20K	2 sec	1:01		
2	Yagi	164K	5 sec	1:01		
3	Yagi	7MB	n/a	1:01	526K	13-27%
4	Parabolic	7MB	45 sec	1:01	1.27MB	
5	Parabolic	35MB	n/a	1:01		
18-Nov-03						
Run No.	**Media**	**Size**	**Time**	**Type**	**Throughput**	**Packet Loss (%)**
1 (Net Meet)	Parabolic	35MB	n/a	1:01	736K	
2 (Net Meet)	Parabolic	7MB	1'23"	1:01	486K	
3	Parabolic	35MB	6 min	1:01		
4	Parabolic	300MB	too long	1:01	792K	
5	Parabolic	7MB	1 min	1:01	800K	

Table 8. RAW DATA YAGI AND PARABOLIC ANTENNAS

The type of cable used for the experiment was coaxial cable along with the Comscope WBC series cable assemblies. The 3/8 inch WBC-400 & WBC-400R 50 coaxial cable assemblies have a maximum bending radius of two inches or fifty millimeters. Attenuation at 2500MHz = 6.8dB/100feet; 3.4dB/50feet; 1.7dB/25feet; .17dB/2.5ft.

Parabolic and yagi antennas were used during the testing. In order to maximize the strength of antenna propagation pattern, it was important to understand the polarization in relation to the positioning of the element with respect to horizontal versus vertical beam widths. When the grid antenna was positioned with horizontal polarization, the horizontal beam width was eight degrees. The respective elevation beam width was three degrees. The parabolic antenna tested was the HyperGain Reflector Grid Antenna, HG2424G[25], which is seen in (Figure 19). The specifications on the antenna are provided below in Table 9.

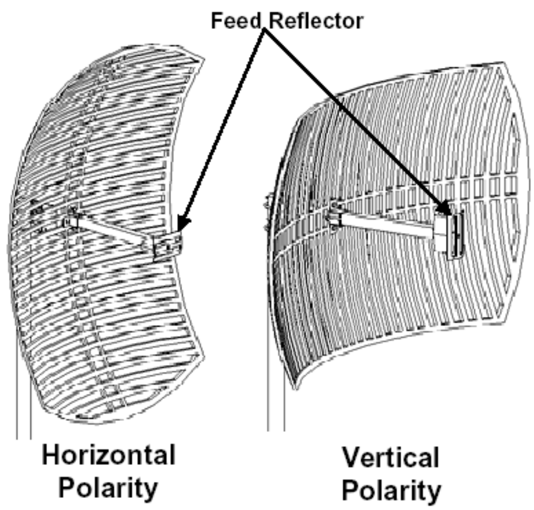

Figure 19. PARABOLIC ANTENNA

Electrical Specifications

Frequency	2400-2500 MHz
Gain	24 dBi
-3 dBi Beam Width	8 degrees
Cross Polarization Rejection	26 dBi
Front to Back Ratio	24 dB
Sidelobe	-20dB Max
Impedance	50 Ohm
Max. Input Power	50 Watts
VSWR	< 1.5:1 avg.

Mechanical Specifications

Weight	4.8 lbs. (2.18 kg)
Grid Dimensions	39.5 in (100 cm) x 23.5 in (60 cm)
Mounting	2 in. (50.8 mm) diameter mast max.
Elevation Angle	0 to +10 degrees
Operating Temperature	-45° C to +85° C

Table 9. PARABOLIC SPECS

[25] http://www.hyperlinktech.com/web/pdf/hg2424g.pdf

The yagi antenna tested was a HyperGain Radome Enclosed Yagi antenna, HG2415Y[26] (Figure 20). The beam width appeared to be 30 degrees regardless of polarization (Table 10).

Figure 20. YAGI ANTENNA

Electrical Specifications

Frequency	2400-2500 MHz
Gain	14.5 dBi
-3 dB Beam Width	30 degrees
Impedance	50 Ohm
Max. Input Power	50 Watts
VSWR	< 1.5:1 avg.

Mechanical Specifications

Weight	1.8 lbs.
Length	19" length x 3" diameter
Radome Material	UV-inhibited Polymer
Mounting	2 3/8" dia. mast max.
Polarization	Vertical
Wind Survival	>150 MPH

Table 10. YAGI SPECS

2. Beyond Line-of-Sight (BLOS)

No BLOS testing was conducted during this experiment. See Field Test #3 (Raytheon) and Field Test #4 (Camp Roberts).

3. Over-the-Horizon (OTH)

No OTH testing was conducted during this experiment. See Field Test #3 (Raytheon) and Field Test #4 (Camp Roberts).

B. FIELD TEST #2 (GENERAL DYNAMICS)

Students from NPS conducted thesis research for Marine Corps Systems Command on January 6-9, 2004 with General Dynamics Decision Systems (GDDS) in Scottsdale, AZ. The actual testing was done on Papago's Arizona National Guard base three miles from GDDS. The following NPS students were involved in the testing event:

[26] http://www.hyperlinktech.com/web/pdf/hg2415y.pdf

Captain David Joseforsky, Captain Gil Garcia, LT Manny Cordero, LT Al Seeman, Captain Dwayne Lancaster, and Captain Chris Cox (USMC).

The students, General Dynamics personnel, and several vendors participated in tactical communications testing for the UOC being built by General Dynamics. The testing compared current state-of-the-art commercial capabilities in the following areas: 1) Wireless technologies, 2) Operational ease of use, 3) Power and environmental considerations, and 4) Communication bandwidths. Each technology was evaluated for COC to COC (inter-nodal) and COC to Antenna Hill (intra-nodal) modes of operation.

The ultimate goal of this testing event was to determine which technologies increase throughput on the battlefield for the UOC program. The following state-of-the-art wireless technologies were tested: Free Space Optics, 802.11b (over SecNet-11), 802.16, and Microwave Link. Voice over Internet Protocol (VoIP) was implemented in the local area networks to test which technologies handled it best. Next, the students demonstrated an OTH capability provided by combining four Iridium satellite channels, similar to the Expeditionary Tactical Communications System. Over this link, the Iridium Inverse Multiplexer and Compression Algorithm, being developed by Dr. Glen Abousleman at Arizona State University, was utilized. Finally, establishing a covered network with General Dynamics' In-Line Network Encryptor, KG-235, was a testing objective.

Figure 21 illustrates the established network at this testing event. Since there were two LANs in this Wide Area Network, the students decided to configure three separate subnets. The MRF setup was a 192.168.1.x subnet, the remote site was 192.168.3.x, and the established link between the two networks was 192.168.2.x. Thus, the Cisco 3745 routers on the edge of the LAN were configured to have the Ethernet port connected to the link as a 192.168.2.1/2 IP address, and the port connected to the switch within the LAN was assigned 192.168.1.1 for the remote site and 192.168.3.1 for the MRF. Next, the Cisco Call Manager Server and the IP Phones were assigned an IP address according to their respective subnet as they came online. The Cisco 3550 switches and DSUs did not have an IP addresses assigned to them.

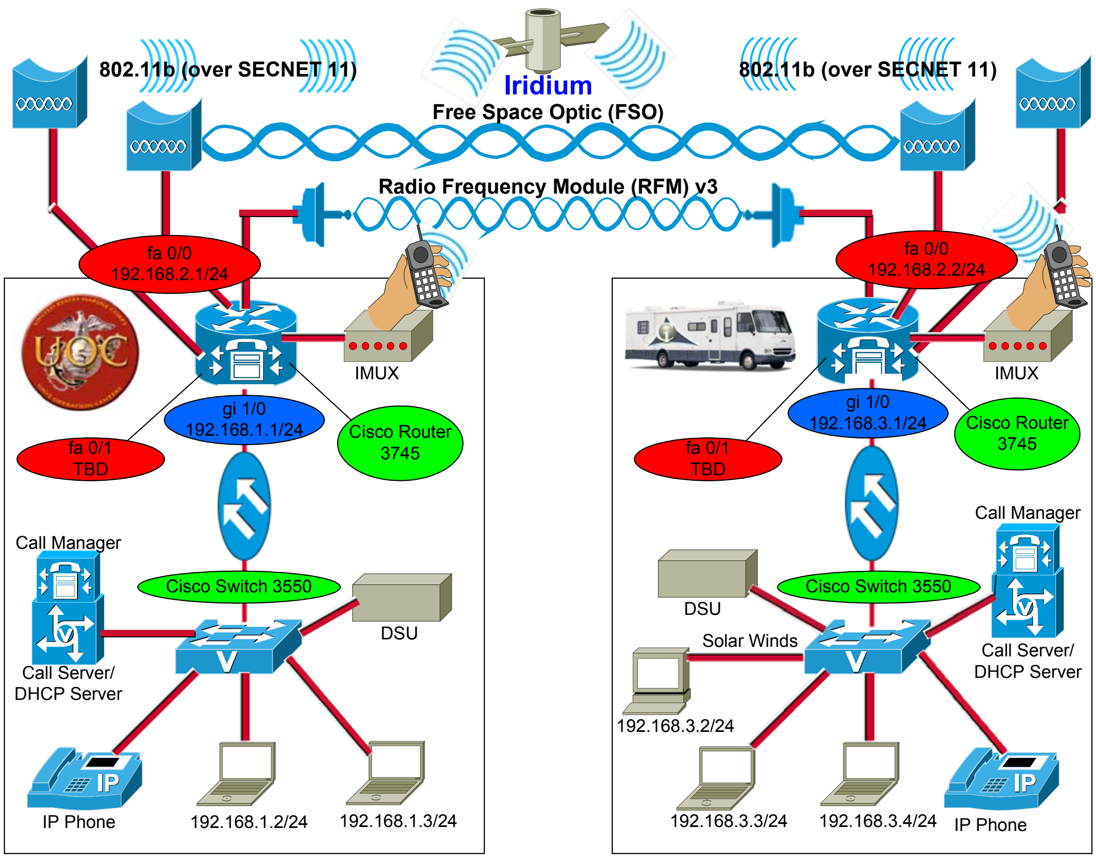

Figure 21. GENERAL DYNAMICS TESTING NETWORK DIAGRAM

The above figure conveys a network without encryption, except when using SecNet-11 over 802.11b. Since the original goal was to establish a covered network, toward the end of the week, General Dynamics' In-Line Network Encryptor, KG-235, was inserted into the network in place of the Cisco 3745 Routers to achieve a covered network. Obtaining this covered network was unsuccessful due to configuration issues with the KG-235. Thus, the entire testing event, except SecNet-11 testing, was done without encryption.

To show the capabilities of each evaluated technology as far as physical distance, the technologies are broken down into three different categories: LOS, BLOS, and OTH.

1. Line-of-Sight (LOS)

a. SecNet-11

SecNet-11 is a product developed by Harris Corporation. It is a secure, NSA Type 1 and FIPS-140 compliant encryption, wireless local area network interface card. National Security Agency's certification of the SecNet-11 card does not include the system software/hardware residing on the host, or the software contained on the CD packaged with the SecNet-11. The SecNet-11 card provides secure communication of data as well as source and destination addresses without the requirement for a hardwired network. The card operates in the unlicensed 2.4 GHz Instrumentation, Science, and Medical (ISM) band and will operate according to the 11 Mbps Institute of Electrical and Electronics Engineers (IEEE) 802.11 protocol with the additional processing time and delay associated with encrypting the header information.[27]

The SecNet-11 uses standard DOD keying material. It accepts only a single red key using the DS-102 protocol. The device can be loaded with UNCLASSIFIED, CONFIDENTIAL, or SECRET keys. SecNet-11 is not currently approved for TOP SECRET. A single red key is loaded into the card via a Data Transfer Device (DTD) (i.e., AN/CYZ 10) using the DS-102 protocol. The same key must be loaded into all local SecNet-11 devices that will intercommunicate.[28]

The SecNet-11 testing for this event was done at 500 meters. As seen above in the General Dynamics Testing Diagram, Figure 21, the 802.11b over SecNet-11 was set up in a point-to-point link. SecNet bridges were used to transmit point-to-point. Each bridge actually takes one of the SecNet cards. Thus, the signal was encrypted between both bridges. The rest of the network was wired locally, so the network was relatively secure. Next, the parabolic antenna described in field test #1 was used as the remote antenna, and it was connected to the SecNet card on the bridge via an N-type cable. A special connector was needed that could screw into the SecNet card on one end and the other end to the N-type cable. Furthermore, the connection between the bridge and the Cisco 3745 router was a CAT-5 cable. Finally, speed settings for the ports on the Cisco routers and switches needed to match the speed of the SecNet bridge. The routers and switches were set to speed 10 vice speed 100 as was done with all the other

[27] Richard C. Shaeffer, Jr., Information Assurance Deputy Director, NSA, "Interim Operational Systems Security Doctrine for the SecNet-11Wireless Local Area Network (WLAN) Interface Card", October 2002.

[28] Richard C. Shaeffer, Jr., Information Assurance Deputy Director, NSA, "Interim Operational Systems Security Doctrine for the SecNet-11Wireless Local Area Network (WLAN) Interface Card", October 2002.

technologies tested in order to prevent a configuration mismatch in the line speed. The devices were set for full duplex.

In order to change the settings on the bridge, the authors needed to connect a computer to a switch or hub via CAT-5 cable and then from the switch or hub to the bridge via CAT-5. Then they could view the Graphical User Interface provided by the software that comes with the bridge. Since the bridges needed special settings, one bridge was set as 'Master' and the other bridge was set as 'Slave'. For this testing, the 'Master' was located at the Mobile Research Facility.

In the table below, the column that is titled 'Size' signifies the size of the data file that was sent from one computer in one network to another computer in the opposite network via Microsoft Windows file sharing. The data files consisted of Word documents, Power Point presentations, and PDF files. There was no video or voice utilized at the time of this testing. The 'From' and 'To' column show the last digits of the computer IP address (192.168.x.x). Table 11 shows the data collected during the SecNet testing at 500 meters.

Run No.	Media	Size	Time	Throughput	Packet Loss (%)	From	To
1	SECNET 11	1.5 M	41"	946K	12%	3.4	1.2
2	SECNET 11	5 M	1'03"	1.06M	10%	3.4	1.2
3	SECNET 11	10 M	3'29"	1.13M	14%	3.4	1.2
4	SECNET 11	25 M	4'05"	1.19M	24%	3.4	1.2
5	SECNET 11	75 M	11'07"	1.13M	17%	3.4	1.2
6	SECNET 11	1.5M	23"	600K	9%	1.2	3.3
7	SECNET 11	5M	1'12"	400K	14%	1.2	3.3

Table 11. RAW DATA SECNET-11 POINT-TO-POINT

In addition to the point-to-point testing accomplished with SecNet-11, data was collected on the use of a SecNet access point within a local area network. In this setup, an access point with a SecNet card was set up in the Mobile Research Facility network with two laptops wirelessly connected to that access point. The laptops each had their own SecNet card inserted. To configure the laptop appropriately with the card's software, the computer had to be in Administrator mode. Finally, the access point was wired into the LAN's switch with CAT-5 cable. Table 12 below shows the data obtained.

Media	Size	Time	Throughput	Packet Loss (%)	From	To	VOICE
SECNET 11	1.5 M	6"	1.2M	0%	3.102	3.103	NO
SECNET 11	5 M	23"	2.1M	0%	3.102	3.103	NO
SECNET 11	10 M	lost	2.1M		3.103	3.102	NO
SECNET 11	10M	53"	2.94M	0%	3.103	3.102	NO
SECNET 11	75 M	1'36"	2.3M	0%	3.102	3.103	NO
SECNET 11	10M	21"	4.94M	0%	3.102	3.102	NO
SECNET 11	10M	30"	3.93M	0%	3.7	3.102	NO

Table 12. RAW DATA SECNET-11 IN LAN

The reason for this testing was that General Dynamic's personnel were interested in knowing how many laptops the access point could handle. Since the students did not have the ability to associate a multitude of laptops to the access point, they accomplished the goal by transferring large files between computers in order to simulate a large volume of throughput in the network. Any size file that was above 75Mb was unsuccessful in its transfer from one computer to another.

b. Radio Frequency Module (RFM)

GDDS provided a RFM v3 system during two days of the testing evolution, January 6 and 8, 2004. Ceragon Networks is the actual producer of the RFM product. However, GDDS packages the product in appropriate cases along with a Cisco 2950 switch for their customers. This case along with the microwave dish is field expedient and hardened to withstand a rugged military environment. The antenna sits on top of a lightweight telescopic stand, which is separate from the case. A distance of 9 kilometers can be reached with the one-foot antenna, which was used during the testing event, and 13.5 kilometers with the two-foot antenna.[29] RFM is a point-to-point, line-of-sight, OC-3 capable (155 Mbps) microwave product. Figure 22 shows the RFM antenna, tripod, and case.

[29] GDDS, "Radio Frequency Module (RFM) v3 Handout", 2003.

Figure 22. GDDS RFM v3

Next, the frequency band that the RFM product utilizes can be found in Table 13 below. Whichever channel is chosen, the transmitting and receiving frequencies are slightly separated in order to avoid any interference.

Channel	TX Freq (MHz)	RX Freq (MHz)
1	14515	14935
2	14543	14963
3	14571	14991
4	14599	15019
5	14627	15047
6	14655	15075
7	14683	15103
8	14711	15131

Table 13. RFM FREQUENCY BANDS

The first day of testing with RFM offered a chance to become familiar with the product and work out any problems. On the second day, it was utilized with MRV's Optical Switch (OptiSwitch) that automatically switches over from FSO to RF if the FSO signal is lost or degraded. The RFM product was tested at 1,000 meters on both days.

During the first day, some minor problems were encountered. Since the RFM equipment was utilizing the Cisco switch found within the carrying case, the ports of the switch were not configured appropriately to match the Local Area Network routers and switches. This equipment was configured for speed 100 (100 Mbps) and full duplex. The RFM Cisco switch was set on auto-negotiation. Cisco products that are not set on the same settings throughout the network will not function properly, which can cause degradation in the networks. Thus, initially the authors were seeing low throughput data for the RFM gathered from Iperf (see appendix for explanation of Iperf), which can be seen in Figure 23 below. Note that Iperf was sending a flood of 64Kb size packets to get this throughput data. At this testing evolution, the authors were unable to change the size of the packets. In the later experiments, the packet size could be changed. The normal throughput capability of the RFM system is OC-3 (155 Mbps) but the router and switch ports could only handle 100 Mbps. In addition to the low throughput data, the link was very unstable and constantly showing as signal lost in SolarWinds network monitoring system (see appendix for full explanation) during the times the RFM Cisco switch was set at auto-negotiation.

```
------------------------------------------------------------
Client connecting to 192.168.1.2, TCP port 5001
TCP window size: 63.0 KByte (default)
------------------------------------------------------------
[928] local 192.168.3.4 port 1034 connected with 192.168.1.2 port 5001
[ ID] Interval        Transfer      Bandwidth
[928]  0.0- 5.0 sec   17.1 MBytes   27.3 Mbits/sec
[928]  5.0-10.0 sec   17.5 MBytes   28.0 Mbits/sec
[928] 10.0-15.0 sec   15.0 MBytes   23.9 Mbits/sec
[928] 15.0-20.0 sec   19.0 MBytes   30.4 Mbits/sec
[928]  0.0-20.0 sec   68.5 MBytes   27.4 Mbits/sec
```

Figure 23. RFM IPERF DATA BEFORE CONFIGURING SWITCH

After getting the RFM Cisco switch port that was connected to the existing network set to speed 100 and full duplex, the data and link were very consistent and stable. SolarWinds showed the link up throughout the rest of the day. The Iperf data after the proper configuration settings can be found in Figure 24 below.

```
------------------------------------------------------------
Client connecting to 192.168.1.2, TCP port 5001
TCP window size: 63.0 KByte (default)
------------------------------------------------------------
[928] local 192.168.3.4 port 1037 connected with 192.168.1.2 port 5001
[ ID] Interval          Transfer       Bandwidth
[928]  0.0- 5.0 sec     32.7 Mbytes    52.2 Mbits/sec
[928]  5.0-10.0 sec     32.7 MBytes    52.3 Mbits/sec
[928] 10.0-15.0 sec     32.8 MBytes    52.5 Mbits/sec
[928] 15.0-20.0 sec     32.5 MBytes    52.0 Mbits/sec
[928]  0.0-20.0 sec     131 MBytes     52.3 Mbits/sec
```

Figure 24. RFM IPERF DATA AFTER CONFIGURING SWITCH

On 8 January, the RFM was utilized with MRV's OptiSwitch. Prior to conducting this testing, more data was collected with SolarWinds on the actual throughput of the RFM link while transferring data files, such as Word documents, Power Point presentations, and PDF files. As it is reflected in the data table below, the link would drop out when attempting to transfer files bigger than 300 Mbytes. However, it was again very consistent and stable for this test for files 300M and smaller. The data from SolarWinds shows a much lower throughput than Iperf because the SolarWinds data was measuring how well files transferred from computer to computer when conducting a Microsoft Windows file sharing session. In addition, the files were very inconsistent in size and type, while Iperf sends packets that are consistent in size and type. See Table 14 for the SolarWinds data.

Run No.	Media	Size	Time	Throughput	Packet Loss (%)	From	To
10	MICROWAVE	1.5M	1"	2.3M	0%	3.4	1.2
11	MICROWAVE	5M	2"	7.3M	0%	3.4	1.2
12	MICROWAVE	10M	2"	15M	0%	3.4	1.2
13	MICROWAVE	25M	7"	36M	0%	3.4	1.2
14	MICROWAVE	75M	17"	40M	0%	3.4	1.2
15	MICROWAVE	300M	1'30"	37M	0%	1.2	3.4
16	MICROWAVE	300M	1'08"	43M	0%	3.4	1.2
17	MICROWAVE	600M	DROP			1.2	3.4

Table 14. RFM SOLARWINDS DATA ON 8 JANUARY

In the FSO-RF switchover test, the RFM Cisco Switch was connected to MRV's OptiSwitch via a CAT-5 crossover cable. The reason for the crossover cable was that two like devices, switches, were connected to each other. With both MRV's FSO product and the RFM connected to the OptiSwitch, the transition from one to the other was seamless. In order to facilitate the FSO signal being lost, a box was placed in front of the FSO link head. There was no packet loss or delay in the transfer of files from computer to computer. When the box was taken away from the link head, the FSO product picked up the transmission again without any delay or noticeable difference in the transition. Again, SolarWinds was used to read the throughput data, and file sharing between computers was the method being used to flood the link with data. Table 15 below shows the data for the FSO-RF test.

Run No.	Media	Size	Time	Throughput	Packet Loss (%)	From	To
19	FSO	300M	1'31"	24M RF, 36M FSO	0%	3.4	1.2
20	FSO	150M	"50	41 RF, 42 FSO	0%	3.4	1.2
21	FSO	75M	"27	6 RF, 30 FSO	0%	1.2	3.4
22	FSO	300M	2'00"	24 RF, 31 FSO	0%	1.2	3.4
23	FSO	600M	4'24"	24 RF, 35 FSO	0%	1.2	3.4

Table 15. FSO-RF SWITCHOVER

c. fSONA

After field test #1, the authors were much more familiar with fSONA's product, SONAbeam 155-M. For this testing evolution, the exact same setup for fSONA's equipment was utilized as the previous testing. The SONAbeam 155-M was connected to a media converter with a single-mode fiber cable. The media converter was outfitted with a SC-fiber connection with RJ-45 out to the network's router. Attempts were initially made to connect fSONA's product directly from the link heads to the network routers with the single-mode cable. The network routers were equipped with a Gigabit Network Interface Module to accept a fiber connection. This configuration of the SONAbeam 155-M directly to the router was unsuccessful. The reason for this was that the single-mode fiber interface on the SONAbeam 155-M was 1310 nanometers. The Gigabit Network Interface Module only accepted 850 nanometer signals from the fiber. Next, the SONAbeam 155-M was set up on the heavy-duty stands that weighed a total of 200 pounds each. This provided the SONAbeam 155-M with a stable platform to mount the product. Finally, fSONA had a separate Alternating Current (AC) to Direct Current (DC) converter. This allowed the link head to be plugged into the power converter with DC power, and then the power converter had a regular AC 120V plug that went into the available generators.

fSONA's testing was conducted at 1,000 meters down an airfield runway. The conditions were ideal with clear skies and sunny weather. Scintillation was much more prevalent during this testing event since the link heads were only six feet off the ground and the runway was black pavement. This is significant because scintillation can cause serious degradation in the laser being sent between link heads. Some testing was also done with the SONAbeam 155-M during the nighttime when there was complete darkness, when scintillation is much less of an issue.

Captain Gilbert Garcia and LT Al Seeman did the setup of the SONAbeam 155-M equipment. Pablo Bandera, fSONA's Product Manager, was available to fine-tune the alignment of the lasers. A voltmeter was used to determine the strength of the signal between the link heads. This established link did not drop once throughout the day and proved to be the most stable FSO link during this event.

Other performance measures were taken during fSONA's allotted time slot on the 7 January 2004. Since fSONA's SONAbeam 155-M product has four transmitting lasers and a large distinctive receiving area, data was gathered when blocking the transmitting lasers one at a time starting with one, then two, and finally blocking three lasers out of the four. In addition, three lasers were blocked along with roughly 95% of the receiver area. A picture of this can be found in Figure 25 below. The lasers on the edges were being blocked with cardboard taped over them and the receiver area was blocked with a pizza box.

Figure 25. PABLO BANDERA, fSONA, BLOCKS LASERS AND RECEIVER

The data collected for the regular testing, blocking lasers, and night testing can be found Table 16 below. As can be seen from the data, the link was very stable no matter the size of the files being transferred. During the night testing, Voice over Internet Protocol was also implemented. There was one phone in each respective network. Each phone required about 90 Kbps of throughput, so it had minimal effect on the performance of the laser link. The files being transferred were again Word documents, Power Point presentations, and PDF files. There was no Iperf data gathered for fSONA during this testing event.

1000 meters	Run No.	Media	Size	Time	Throughput	Packet Loss	From	To
DATA	1	FSO	1.5 M	n/a	2.2M	0%	1.2	3.3
	2	FSO	5 M	2"	6.2M	0%	1.2	3.3
	3	FSO	10 M	3"	15M	0%	1.2	3.3
	4	FSO	25 M	5"	34M	0%	1.2	3.3
	5	FSO	75 M	17"	39M	0%	3.4	1.2
	6	FSO	150 M	39"	39M	0%	3.4	1.2
	7	FSO	300 M	1'15"	34M	0%	3.4	1.2
	8	FSO	150M	28"	54M	0%	1.2	3.3
	9	FSO	300M	57"	56M	0%	1.2	3.3
	10	FSO	600M	2'58"	47M	0%	1.2	3.4
	11	FSO	1.2G	5'20"	54M	0%	1.2	3.4
1 lasers blocked	12	FSO	300M	1'13"	44M	0%	1.2	3.4
2 lasers blocked	13	FSO	300M	1'15"	50M	0%	1.2	3.4
3 lasers blocked	14	FSO	300M	1'15"	50M	0%	12	3.4
lasers/receiver blocked	NO DATA GATHERED, LINK DID NOT DROP							
VOICE AND DATA								
NIGHT TESTING	10	FSO	1.5 M	N/A				
	11	FSO	5 M	2"	7M	0%	1.2	3.4
	12	FSO	10 M	3"	15M	0%	1.2	3.4
	13	FSO	25 M	5"	37M	0%	1.2	3.4
	14	FSO	75 M	20"	31M	0%	3.4	1.2
	15	FSO	300M	1'20"	42M	0%	1.2	3.4
	16	FSO	300 M	1'35"	30M	0%	3.4	1.2
	17	FSO	600 M	3'15"	44M	0%	1.2	3.4
	18	FSO	1.2 GIG	6'05"	46M	0%	1.2	3.4

Table 16. FSONA DATA 7 JANUAY

d. MRV

Tim Kcehowski, Director of Federal Sales, Levon Fayson, Technical Support Engineering Manager, and Isaac Kim, Director of FSO, from MRV Communications supported this testing event. Mr. Fayson was instrumental in setting up the Terescope 3000 OC-3 link heads. The distance between both sites was 1,000 meters over a black pavement runway, and the weather was ideal with clear skies and a temperature in the 70-degree range.

The Terescope 3000 OC-3 specifications state that it can reach out to 4 kilometers with a 3 dB loss per one kilometer, which would equate to light haze, and still provide 99.999% reliability.[30]

MRV also brought along with them their OptiSwitch that automatically switches over from FSO to RF when the FSO link is lost. The MRV TereScope product supports a patent optional software feature called "Terescope Fusion". This feature

[30] Isaac Kim, "Terescope Free Space Optics Overview Brief", 2003.

provides auto switch over from the TereScope product to any back up RF system. The software in the Terescope communicates with the MRV manufactured OptiSwitch product to provide switching between the FSO and backup RF system. The OptiSwitch also has unique software to communicate with the Terescope. The RFM product was used as the backup RF system during this testing event. Figure 26 below demonstrates MRV's OptiSwitch used during the testing event.

Figure 26. MRV OPTISWITCH 200

From the Terescope 3000, there was a multi-mode fiber cable that ran to the media converter that MRV brought with them. The media converter had an RJ-45 connection that went from the converter to the network's 3745 router. Next, there was a AC to DC converter, separate from the link head, which allowed the DC powered link head to be plugged into the available AC 120V power source on the generators.

The Terescope 3000 alignment process was done via a camera located within the Terescope. This camera is capable of seeing the laser light from the other link head. One can view what the camera is seeing on a display that is separate from the actual link head. The video alignment software is built into the TereScope product, and it can be remotely viewed by extending the video back to the user in the Operations Center. Once the camera sees the laser light from the other link head, one can manually move the link head to get the laser light in the center of the cross hairs on the video display. The alignment process was relatively simple once viewed on the display screen. See Figure 27 below to view MRV's Terescope 3000 and the display screen for the alignment. The camera feature can also be viewed on other sources such as laptops and palm pilots by taking either a CAT 5 cable or fiber connection out of the Scope to the network equipment. In addition to the patent MRV video alignment, MRV is adding tracking and auto alignment into their units.

Figure 27. MRV TERESCOPE 3000 W/ ALIGNMENT DISPLAY

Throughput data was collected on the Terescope 3000 via file sharing on Microsoft Windows and packet flooding on Iperf. The data collected was inconsistent, with considerable packet loss when transferring large files. In addition, no files larger that 300 Mbytes could be transferred between computers on the different networks. Table 17 below shows the file sharing data collected utilizing SolarWinds as the measuring tool.

1000 meters DATA	Run No.	Media	Size	Time	Throughput	Packet Loss	From	To
	1	FSO	1.5 M	1"	2.2M	0%	3.4	1.2
	2	FSO	5 M	2"	7.3M	0%	3.4	1.2
	3	FSO	10 M	5"	9M	0%	1.2	3.3
	4	FSO	25 M	7"	27M	0%	3.4	1.2
	5	FSO	75 M	34"	25M	0%	1.2	3.3
	6	FSO	150 M	drop				
	7	FSO	300 M	1'54"	25M	15%	1.2	3.3
	8	FSO	600 M				1.2	3.3
	9	FSO	1.2 GIG					
VOICE AND DATA								
	10	FSO	1.5 M	1"	2.3M	7%	3.4	1.2
	11	FSO	5 M	2"	7.3M	0%	1.2	3.3
	12	FSO	10 M	7"	11M	0%	1.2	3.3
	13	FSO	25 M	20"	10M	0%	1.2	3.3
	14	FSO	75 M	31"	23M	20%	3.4	1.2
	15	FSO	150 M	drop				
	16	FSO	300 M	4'00"	16M	0-4%	1.2	3.3
	17	FSO	600 M					
	18	FSO	1.2 GIG					

Table 17. MRV DATA 8 JANUARY

The throughput readings were low for a system that is capable of OC-3 rates (limited to 100 Mbps due to the network ports). After getting these readings, considerable time was spent on troubleshooting the problem. It was believed that the settings on the media converter were incorrect, so calls were made back to MRV's office. After establishing what was believed to be the right settings, the authors set up laptops off of the link heads through the media converters on both sides and used Iperf to gather the throughput data. This data can be found in Figure 28 below.

```
------------------------------------------------------------
Client connecting to 192.168.64.221, TCP port 5001
TCP window size: 63.0 KByte (default)
------------------------------------------------------------
[928] local 192.168.64.220 port 1083 connected with 192.168.64.221 port 5001
[ ID] Interval        Transfer      Bandwidth
[928]  0.0- 5.0 sec   33.0 MBytes   52.7 Mbits/sec
[928]  5.0-10.0 sec   32.9 MBytes   52.6 Mbits/sec
[928] 10.0-15.0 sec   32.9 MBytes   52.7 Mbits/sec
[928] 15.0-20.0 sec   32.9 MBytes   52.6 Mbits/sec
[928]  0.0-20.0 sec   132 MBytes    52.7 Mbits/sec
```

Figure 28. MRV IPERF DATA 8 JANUARY

While this data shows a big improvement from the previous experiment with SolarWinds, it was still low for a connection between computers. The established networks were not involved, which usually slows the throughput down at least 10%. When MRV went back to their labs after the testing event, they determined that the media converters were not set properly, as they attained throughput near 100 Mbps in the labs.

The FSO-RF switchover with the OptiSwitch was a huge success. Both the Terescope 3000 and the RFM were connected to the OptiSwitch with CAT-5 cable; and the FSO link was going through the media converter. The Terescope Fusion in conjunction with the OptiSwitch was set to have the FSO link as the priority link, so that was the link that would be used unless the FSO link was lost. This type of setup proves beneficial for situations when the weather is unpredictable. If fog rolls in and the link is at 1,000 meters, then the OptiSwitch will eventually start to sense the power level of the link being insufficient to get to the other side. At this point, the RF link would take over. For this testing event, since the weather was ideal, a box was placed in front of the Terescope to drop the FSO link and demonstrate how the RF picks up the connectivity. After a short while, the box was taken away from the FSO link and the Terescope came back up as the priority link. The data collected during this testing was from SolarWinds and it can be found in Table 18 below.

Run No.	Media	Size	Time	Throughput	Packet Loss (%)	From	To
19	FSO	300M	1'31"	24M RF, 36M FSO	0%	3.4	1.2
20	FSO	150M	"50	41 RF, 42 FSO	0%	3.4	1.2
21	FSO	75M	"27	6 RF, 30 FSO	0%	1.2	3.4
22	FSO	300M	2'00"	24 RF, 31 FSO	0%	1.2	3.4
23	FSO	600M	4'24"	24 RF, 35 FSO	0%	1.2	3.4

Table 18. MRV AND RFM W/ MRV'S OPTISWITCH

Large file transfers were used to extend the time it took to accomplish the transfer. This assisted the authors in viewing the capability of the OptiSwitch and for them to see if the transfer was interrupted or if any packet loss occurred. Neither of these situations took place.

e. Lightpointe

Lightpointe's team consisted of Jim McGowan, Sales Director, and Albert Borquez, Network Engineer. They brought their FlightStrata Gigabit Fly Away Package with them, which consisted of one ruggedized travel case per link head and accessories. This whole case weighs about 70 pounds and is easily rolled around via a handle and wheels attached to the case. The FlightStrata transmits four redundant beams of light that overlap and adjust via Multi-Beam Array Tracking (MBAT) technology. The system also has an Automatic Power Control feature that allows the link head to automatically adjust its power output based on the situation with weather or distance.[31] Finally, the link head sits on top of a lightweight, three-foot, telescopic tripod that fits into the traveling case.

The setup was fast and simple. The FlightStrata proved to be the easiest to set up out of all FSO products. After setting up the stand, the link head was attached to the top with four screws. There was also a separate box for the AC to DC power conversion to facilitate an AC 120V plug-in to the generators. Furthermore, the alignment was simple but not the most advanced feature. The scope to find the other end was built-in to the link head. After getting close to the alignment, the Light Emitting Diode (LED) indicator on the back of the link head was utilized as the link head was manually adjusted to try and obtain the strongest signal. This was signified by the amount of LED bars that lit up. It was best to do this one side at a time and to have voice contact with the other side in order to get feedback from them as to what their LED bars were indicating.

During this testing evolution, Lightpointe utilized multi-mode cable from their FlightStrata directly to the network's Gigabit Interace Modules on the Cisco 3745 routers. This allowed them to avoid using the media converters. Lightpointe was the only FSO company able to connect their link head directly to the router with fiber throughout the week. The data results were very stable and the throughput was greater than other companies mostly due to the direct fiber connection to the router from the FlightStrata. Table 19 below shows the results obtained from SolarWinds throughout the day while doing file transfers, file transfers and VoIP, and file transfers and VoIP while blocking lasers.

[31] http://www.lightpointe.com/index.cfm/fuseaction/products.flightstrata (April 2004).

1000 meters DATA	Run No.	Media	Size	Time	Throughput	Packet Loss	From	To
	1	FSO	1.5 M	1"	2.3M	0%	3.4	1.2
	2	FSO	5 M	1"	7.3M	0%	3.4	1.2
	3	FSO	10 M	1"	15M	0%	1.2	3.3
	4	FSO	25 M	5"	31M	0%	3.4	1.2
	5	FSO	75 M	15"	53M	0%	1.2	3.3
	6	FSO	150 M	27"	53M	0%	3.4	1.2
	7	FSO	300 M	1'03"	56M	0%	1.2	3.3
	8	FSO	600 M	NOT ATTEMPTED				
	9	FSO	1.2 GIG	5'00"	50M	0%	3.4	1.2
VOICE AND DATA								
	10	FSO	1.5 M	1"	2.3M	0%	3.4	1.2
	11	FSO	5 M	1"	7.4M	0%	3.4	1.2
	12	FSO	10 M	1'	15M	0%	3.4	1.2
	13	FSO	25 M	4'	15M	0%	3.4	1.2
	14	FSO	75 M	15"	47M	0%	3.4	1.2
	15	FSO	150 M	32"	54M	0%	1.2	3.4
	16	FSO	300 M	54"	48M	0%	3.4	1.2
	17	FSO	600 M	2'20"	53M	0%	3.4	1.2
	18	FSO	1.2 GIG	5'02"	55M	0%	3.4	1.2
1 LASER BLOCKED	19	FSO	300M	56"	61M	0%	3.4	1.2
2 LASERS BLOCKED	20	FSO	300M	52"	54M	0%	3.4	1.2
3 LASERS BLOCKED	21	FSO	300M	49"	55M	0%	3.4	1.2

Table 19. LIGHTPOINTE DATA 9 JANUARY

As one can see, the link was able to handle any size file transfer without packet loss, and a subset of the lasers being blocked had no negative effect on the link. Below in Figure 29 are the results from Iperf when 64 Kbyte size packets were flooding the link.

```
------------------------------------------------------------
Client connecting to 192.168.1.2, TCP port 5001
TCP window size: 63.0 KByte (default)
------------------------------------------------------------
[928] local 192.168.3.4 port 1148 connected with 192.168.1.2 port 5001
[ ID] Interval          Transfer       Bandwidth
[928]  0.0- 5.0 sec     50.1 MBytes    80.1 Mbits/sec
[928]  5.0-10.0 sec     50.0 MBytes    80.1 Mbits/sec
[928] 10.0-15.0 sec     50.4 MBytes    80.7 Mbits/sec
[928] 15.0-20.0 sec     50.4 MBytes    80.5 Mbits/sec
[928]  0.0-20.0 sec     201 MBytes     80.3 Mbits/sec
```

Figure 29. LIGHTPOINTE IPERF DATA

Lightpointe's Iperf data was the strongest throughout the entire week. The link did tend to drop a couple of times for a few seconds possibly due to cars driving down the runway in the line of the laser link, dust being kicked up by the cars, or scintillation from the sun hitting the black runway. In addition, the sporadic link drop could have been due to Lightpointe's tripod stand being only 3 feet off the ground, the lowest out of all the companies.

f. Ensemble

Ensemble Communications supported this evolution with Jeff Nightingale, Sales Director, Corey Koberg, Engineer, and Jerry Shirey, Field Technician. They brought equipment that utilizes 802.16 technology. 802.16 is made for Wide Area Networks (WAN), much like 802.11x is utilized in Local Area Networks. In the commercial sector, 802.16 is used for backhaul broadband wireless connectivity for many service providers. IEEE has already developed standards for 802.16a (2-11 GHz) and 802.16c (10-66 GHz). The reason this technology is made for Wide Area Networks (WAN) is because of its point-to-multipoint features. The equipment comes in the following parts: hub station, multiplexer, and antenna. At the hub station, Ensemble can use 60, 90, and 180-degree antennas to provide 360-degree coverage to the remote stations. The remote stations have the multiplexer with their own appropriate type of sector antenna. Ensemble's products operate on the Asynchronous Transfer Mode (ATM) protocol.[32] A new product line is being developed to support Internet Protocol.

Since Ensemble's system was ATM based, the authors attained a Single port ATM OC-3 Single-mode Intermediate Reach NM card for the Mobile Research Facility's 3745 router. The 16200 Hub Station was connected to the port on the card with a single-mode fiber cable. The 320 Multiplexer was on the other end, connected to the 3745 router with CAT-5 cable. A Fiberless 282 Series Outdoor Mounted Unit (ODU) was utilized for the antenna. It operates in the 27.50 to 28.55 GHz range. Other ODU's can be utilized which can operate in the 24 to 40 GHz range.[33] A special frequency request was sent to the Navy/Marine Corps Spectrum Center to get temporary

32 http://www.ensemble.com/product/index.asp (April 2004).

33 Ensemble Communications, "Fiberless Integrated Antenna and Radio Outdoor Unit", December 2003.

authorization to utilize the frequency band in order to operate the 282 Series ODU. As mentioned earlier, the antennas mostly function in a point-to-multipoint environment. However, in this testing only point-to-point was attempted utilizing the 90-degree sector antennas at both sites.

To further explain Ensemble's product capabilities, the ODUs communicate between the hub station and multiplexer sites using the company's revolutionary, patented Adaptix broadband airlink technology to maximize system capacity and efficiency in real time. Physical layer Adaptix features include both Adaptive Time Division Duplexing (TDD) and Adaptive Modulation. Adaptive TDD uses a single RF channel for both upstream and downstream communications and permits the system to adapt in real-time to the exact asymmetry of subscriber traffic burst by burst. Adaptive TDD also fits easily into the many different kinds of spectrum allocations worldwide including block, paired, and split band frequency licenses. The ODU's excellent phase noise characteristics enable the system to support not only QPSK and 16QAM, but also 64QAM operation burst by burst.[34]

Ensemble's link was set up to attain a maximum throughput of 66 Mbps with that being split between the two-way traffic. Thus, if both sites were sending data at the same time, then each flow of traffic would be allotted 33 Mbps of throughput. Next, the setup of the equipment required detailed configuration of the router at the hub station's site. This ended up taking approximately six hours of work with several individuals working on the configuration. The ATM configuration proved to be much more complex than Internet Protocol, which was used by all the other companies.

Data was collected in SolarWinds for the throughput capabilities of Ensemble's equipment. Again, data file transfers were conducted between laptops on the two networks, and VoIP was being utilized during these transfers. See Table 20 below for this data.

[34] Ensemble Communications, "Fiberless Integrated Antenna and Radio Outdoor Unit", December 2003.

Run No.	Media	Size	Time	Throughput	Packet Loss (%)	From	To
1	802.16	1.5 M	1"	2.3M	0%	3.4	1.2
2	802.16	5 M	13"	4.42M	0%	1.2	3.4
3	802.16	10 M	25"	5.4M	0%	1.2	3.4
4	802.16	25 M	50"	5.0M	0%	1.2	3.4
5	802.16	75 M	1'07"	12M	9%	3.4	1.2
6	802.16	150 M	5'15"	5M	0%	1.2	3.4
7	802.16	25M	"22	11M	0%	3.4	1.2
8	802.16	75M	1'00"	11M	0%	3.4	1.2
9	802.16	150M	3'05"	11M	0%	3.4	1.2

Table 20. ENSEMBLE 802.16 DATA 8 JANUARY

After analyzing the data, it was evident that the yielded throughput data was low compared to the other technologies. However, since the channel capacity was about 33 Mbps one way, this data compares similarly with the other companies observed throughput as a proportion of maximum channel capacity. The other companies were attaining 40-60% capability of the link while connected to the LANs and also conducting Microsoft Windows file sharing.

Below in Figure 30 is the throughput data from Iperf that was obtained by flooding Ensemble's link with 64 Kbyte size packets.

```
------------------------------------------------------------
Client connecting to 192.168.1.2, TCP port 5001
TCP window size: 63.0 KByte (default)
------------------------------------------------------------
[928] local 192.168.3.4 port 1033 connected with 192.168.1.2 port 5001
[ ID] Interval       Transfer     Bandwidth
[928]  0.0- 5.0 sec   6.3 MBytes   10.1 Mbits/sec
[928]  5.0-10.0 sec   6.4 MBytes   10.2 Mbits/sec
[928] 10.0-15.0 sec   6.4 MBytes   10.2 Mbits/sec
[928] 15.0-20.0 sec   6.4 MBytes   10.3 Mbits/sec
[928]  0.0-20.0 sec  25.5 MBytes   10.2 Mbits/sec
```

Figure 30. ENSEMBLE IPERF DATA 8 JANUARY

Note: Ensemble Communications decided to shut down the company in April 2004.

g. Digital Switch Unit (DSU)

One of the main reasons for conducting an experiment in Scottsdale, AZ was to work with the UOC team and their equipment. The Digital Switch Unit (DSU) is the heart of how the UOC will operate in the future. This system provides the user access, from a laptop or an operator access unit, to all available voice circuits (radio and telephone). The connectivity is obtained by connecting the laptop to one of the Jackboxes available at each operator station. Control of the communication devices is through a Graphical User Interface (GUI) software application resident on the laptop. This provides the button to access the Public Switched Telephone System (PSTN), Plain Old Telephone System (POTS) and any radios connected to the Communications net.[35] A VoIP intercom system will also be available to use through the DSU. From the laptop, the user has the ability to call anyone in the LAN through the GUI. Additionally, this arrangement can be used in the COC to Antenna Hill scenario.

During this testing evolution, the UOC team first brought out their Engineering Development Model DSUs to set up within the respective LANs. After some trouble with the configuration the first few days, a decision was made to use the Low Rate Initial Production DSUs. On Friday, January 9, the DSUs were connected to the LANs with success.

The setup of the UOC equipment at the Mobile Research Facility was relatively straightforward. The General Dynamics' Panasonic Toughbooks were connected to the LAN Cisco 3550 switch with CAT-5 cable, and the DSU was also connected to the LAN Cisco 3550 switch with CAT-5 cable. This was the same setup for the other LAN. The link between the two LANs was Lightpointe's FSO product, FlightStrata-G. On the Toughbooks, there was a GUI available to make VoIP calls within either LAN. Utilizing the GUI was a success while communicating across the network. The quality of the voice transmissions was excellent and there seemed to be no delay.

The disadvantage of this setup was that the two LANs needed to be on the same subnet in order for the DSUs to work effectively. This would be sufficient for a COC to Antenna Hill scenario, but if attempting to go from COC to COC this would not be a realistic option. Further research needs to be done into the Internet Protocol addressing scheme with the DSUs.

---

35 General Dynamics Decision Systems, "UOC Summary Brief", 2003.

h. Voice Over Internet Protocol (VoIP)

The authors were able to expand upon their thesis research objectives after conferring with other students at the Naval Postgraduate School. This research team recognized the various potential benefits of bringing in another student that was doing VoIP thesis research. LT Manny Cordero was able to easily merge his thesis objectives into the author's testing events. Since the authors were already planning on setting up two LANs to test the different transformational technologies, LT Cordero implemented his equipment right into the network. Consequently, LT Cordero was able to see how VoIP reacted to the different types of throughput capabilities. The authors were able to attain a Cisco Call Manager Server, MCS-7825H-2.2 EVV1 model, and two 7960G VoIP telephones from Cisco for the VoIP testing. The 7960G phone can be seen in Figure 31 below.

Figure 31. CISCO VOIP 7960G PHONE

Once at GDDS, Don Lesmeister, the coordinator of the testing event at General Dynamics, provided additional Cisco 7940G and 7960G telephones due to the two telephones originally attained having different protocol loads. Tony Cordaro from Ocean Systems Engineering Corporation (OSEC) was also instrumental in providing support to LT Cordero in getting the VoIP functional. Mr. Cordaro normally assists the

UOC team with their network setup, so Don Lesmeister invited him to Scottsdale to observe this testing evolution.

As mentioned earlier, a mixture of Cisco 7940G and 7960G IP telephones were used to provide voice service throughout the network. The phones took a simple CAT-5 cable connection, while the other end was connected to the LAN Cisco 3550 switch. The Call Manager server was always located in the MRF. The phones throughout the two LANs first talked to the server before making a call to another phone within the network. The server was connected to the MRF Cisco 3550 switch via CAT-5 cable. Each phone and server was assigned its own unique IP address.

Once the phones established connectivity, the authors were able to measure the throughput of a VoIP phone call. SolarWinds was able to monitor the LAN routers, so it measured throughput during a phone call. A call between two phones took up about 90 Kbps of throughput. During this testing event, the students were unable to establish more than one phone within the LANs due to equipment limitations. With the technologies being tested, the available throughput far exceeded the requirement of the phone call so the Quality of Service was excellent. The VoIP protocol employed was Cisco's Call Manager Skinny Client Control Protocol (SCCP). SCCP is a Cisco proprietary protocol used between Cisco Call Manager and Cisco VoIP phones (7940G and 7960G IP phones). Other vendors also support this protocol. The Cisco IP Phones 7960G and 7940G are also capable of supporting other protocols such as Session Initiated Protocol (SIP) and Media Gateway Control Protocol (MGCP).

i. Crypto (KG-235 In-Line Network Encryptor (INE))

GDDS provided two KG-235 Sectéra In-Line Network Encryptors (INE) and a trained operator from the company, Russ Harris, to set them up. GDDS is actually the manufacturer of this product as well. The intent of using these devices was to secure the link between the two LANs and to measure if there was any noticeable difference in the throughput with the encryption applied.

The Sectéra INE is specifically designed to support IP/Ethernet operating over standard commercial networks that require U.S. Government Type 1 security, but it is also used in the military environment. The Sectéra INE protects all levels of data, from

Government Classified to TS/SCI. It provides confidentiality, data integrity, peer identification, authentication and mandatory/discretionary access control services. The Sectéra INE is software configured, using the new Sectéra INE Configuration Manager and is keyed using material supplied by the U.S. Government's Electronic Key Management System (EKMS), for Type 1 products.[36] The Communications Interfaces on the KG-235 are two RJ-45 10/100 Base T and two DB-9 Serial Ports. The INE can support up to 20 Mbps of aggregrate data throughput[37] with further planned upgrades making that number even higher.

The INEs were inserted between the technology link and the LAN Cisco 3550 switch on both LANs. To make the KG-235s work properly within the network, they had to replace the LAN Cisco 3745 routers. The KG-235s actually function as a router, but when assigning the IP addresses to the two KG-235s they needed to be on the same subnet in order for the two networks to see each other. Finally, one of the two Ethernet ports on the KG-235s was used to go to the link equipment with CAT-5 cable and the other one went to the LAN Cisco switch, also with CAT-5 cable. The laptops were also connected to the switch, and they needed to have an IP address of the same subnet as the KG-235s.

Due to some network configuration problems with the KG-235s and one of them constantly dropping its fill, the authors were unable to attain any data with the KG-235s.

2. Beyond Line-of-Sight (BLOS)

Since this testing evolution at GDDS was still at the beginning stages of the author's testing phase, they had not yet interacted with any commercial vendors that produced BLOS technology. Later field tests, #3 and #4, demonstrated an Orthogonal Frequency Division Multiplexing (OFDM) technology that was able to do terrestrial BLOS. Refer to those testing evolutions for the results.

3. Over-the-Horizon (OTH)

With this being the first major testing event planned, OTH capable technologies had not yet been researched thoroughly. However, GDDS did offer their services in this

[36] http://www.gdc4s.com/Products/sectera.htm (April 2004).

[37] http://webhome.idirect.com/~jproc/crypto/kg235.html (April 2004).

area to at least demonstrate an OTH capability between the two LANs. They worked with Dr. Glenn Abousleman from Arizona State University (glen.abousleman@gdds.com) in order to utilize the existing Iridium satellite architecture to its fullest capabilities. Dr. Abousleman's work has focused on utilizing a compression algorithm over this limited throughput mode of transmission. The following paragraphs further explain this capability and how it is encrypted with General Dynamics' INE.

a. Iridium Inverse Multiplexer (IMUX)

A single Iridium channel can only transfer data at 2.4 kbps (not sufficient for image and video transmission). Reachback IMUX combines four 2.4 Kbps Iridium channels to increase overall bandwidth to 9.6 Kbps.[38] The four L-Band transreceivers actually feed into an IMUX box that can be seen in the Figure 32 below.

Figure 32. IMUX[39]

There are three modes of operation for the IMUX: Data, Video, and Voice transmission mode. The data mode ensures data is not altered during transmission (data files, critical imagery, etc.). The video transmission mode can do real-time video transmission using custom video compression software (used when loss of video quality can be tolerated). Finally, in Voice mode each Iridium channel can be used as a satellite telephone.[40]

The compression algorithm that Dr. Abousleman developed can significantly reduce the size of pictures and video to transmit over the limited throughput Iridium links. Through this compression, the user can actually select what parts of a picture or video to compress, such as background around the main area of interest, and what parts to not apply the compression to, such as a target of interest. After

[38] Dr. Glen Abousleman, "Iridium Inverse Multiplexer (IMUX) Brief", October 2003.

[39] Dr. Glen Abousleman, "Iridium Inverse Multiplexer (IMUX) Brief", October 2003.

[40] Dr. Glen Abousleman, "Iridium Inverse Multiplexer (IMUX) Brief", October 2003.

compressing, Dr. Abousleman demonstrated to the authors in a prior visit that the transmission takes only seconds to go from one computer, through the satellite links, and down to another computer.

During this testing evolution, problems occurred with the one of the IMUX ports that feeds into the Iridium transceiver and one of the KG-235s kept dropping its fill. Thus, no data was collected with the Iridium link. Refer to Field Test #3 at Raytheon to read about the success of this experiment.

b. Crypto (KG-235 INE)

General Dynamics' KG-235 INE was explained in detail above. The KG-235 is needed to encrypt and decrypt the Iridium satellite link. The KG-235 was programmed with IP addresses exactly the same as mentioned above for the LAN to LAN communication. Figure 33 demonstrates the setup that was planned for this testing evolution with the IMUX. The only difference between the actual setup and the picture was that the Cisco 3550 switch was between the clients and INE. This type of setup was successful at Field Test #3 at Raytheon. See the next section for this information.

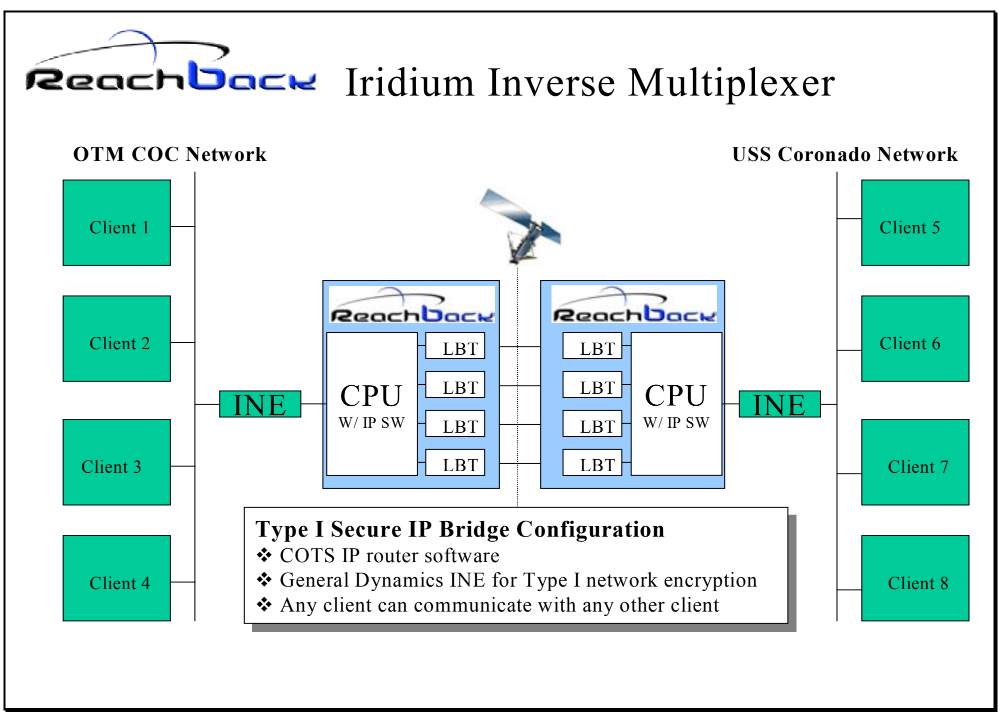

Figure 33. IMUX WITH INE INSERTED[41]

In summary, this testing evolution at General Dynamics in Scottsdale, AZ proved to be a significant learning experience for the authors as several companies presented their products for demonstration; and they connected to existing LANs that were put together by the students. The technologies evaluated were 802.11b over SecNet-11, Microwave, FSO, 802.16, and Iridium. In addition, DSUs and VoIP were inserted with success. Finally, the Iridium links with IMUX and the KG-235s did not meet expectations. However, a great deal of information was obtained and later used in order to accomplish the various goals in the next field test at Raytheon.

C. FIELD TEST #3 (RAYTHEON)

Four students (Captain Garcia, Captain Joseforsky, Lieutenant Seeman, and Lieutenant Cordero) from the Naval Postgraduate School conducted the third field test for Marine Corps Systems Command. On February 2-6, the students, along with Raytheon and several vendors, participated in communications testing for the Common Aviation Command and Control System (CAC2S), a product being built by Raytheon. The testing compared current state-of-the-art commercial wireless technologies in the following areas: operational ease of use, power and environmental considerations, and communication bandwidth. Each technology was evaluated for CAC2S node to CAC2S node and for sub-system intra-nodal connectivity. In particular, the students evaluated sub-system connectivity from the Processing and Display Subsystem (PDS) to the Communications Subsystem (CS) and sub-system connectivity from the PDS to the Sensor and Data Subsystem (SDS). The ultimate goal for field test three was to determine which technologies would increase throughput on the battlefield at a distance greater than six kilometers. The following connectivity diagram was utilized with each technology providing the connectivity between the two separate LANs (Figure 34).

[41] Dr. Glen Abousleman, "Iridium Inverse Multiplexer (IMUX) Brief", October 2003.

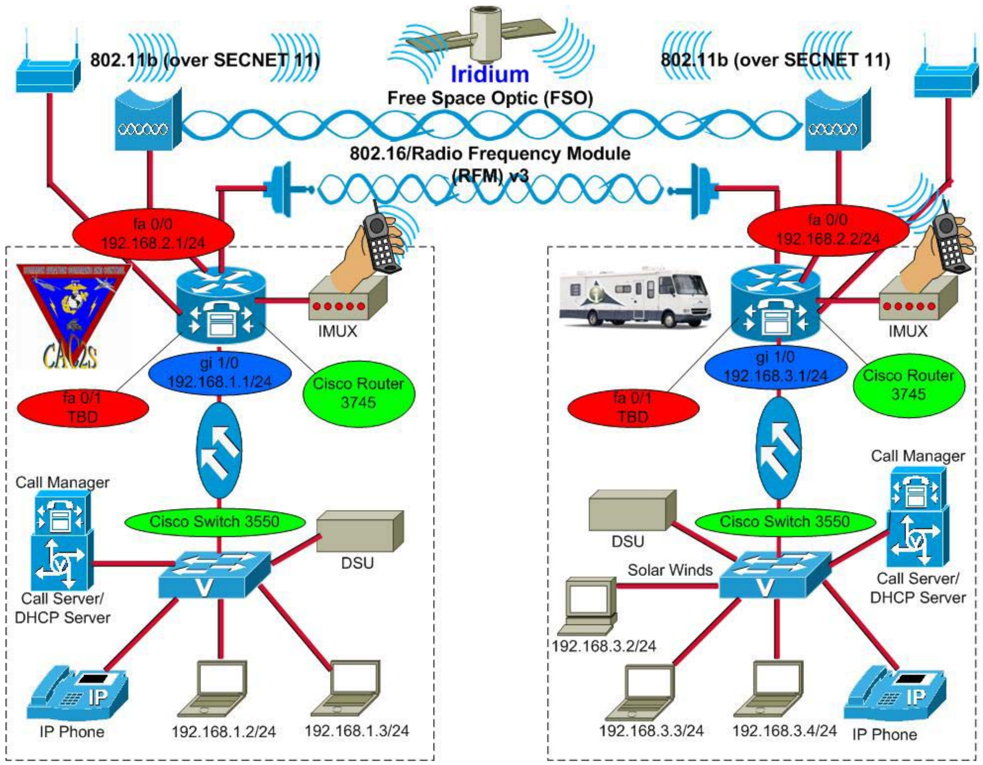

Figure 34. RAYTHEON CONNECTIVITY DIAGRAM

The following state-of-the-art wireless technologies were tested: Free Space Optics, 802.11b (over SecNet-11), 802.16, Orthogonal Frequency Division Multiplexing (OFDM), and Microwave Link. Voice over Internet Protocol (VoIP) was implemented in the local area networks to test which technologies handle VoIP best. Finally, the students demonstrated a BLOS/OTH capability provided by combining Iridium satellite channels. This technology is used in the Marine Corps Warfighting Lab's Expeditionary Tactical Communications System. Over the Iridium link, the Iridium Inverse Multiplexer (IMUX) and Compression Algorithm, being developed by Dr. Glen Abousleman, was utilized. The figure below is a picture of some of the wireless technologies examined at Raytheon testing, the products are (from left to right) the Iridium antenna for the IMUX, RFM, MRV's Terescope 5000, and the parabolic antenna for 802.11b over SecNet-11 (Figure 35).

Figure 35. REMOTE SITE WIRELESS TECHNOLOGIES AT RAYTHEON

One of the lessons learned from the General Dynamics testing was to use an industry standard method in order to measure throughput over the link being tested. The industry standard measurement used was SmartBits by Spirent Communications. The SmartBits analysis system is the industry standard for high port density testing.[42] According to the Spirent web site, "SmartBits enables you to test, simulate, analyze, troubleshoot, develop, and certify network infrastructure."[43] Prior to actual testing at Raytheon, the students were able to get a few days of hands-on SmartBits training. The capabilities and analysis results were explained and demonstrated (one time) by Spirent personnel. The SmartBits system consisted of two chassis that simulated data, voice, and video among several users. With this new tool in-hand, the students were ready to conduct some testing at Raytheon.

The following paragraphs will explain each technology by either LOS, BLOS, or OTH chronologically.

1. Line-of-Sight (LOS)

a. Lightpointe

42 http://www.spirentcom.com/analysis/product_line.cfm?wt=2&az-c=pl&PL=33

43 http://www.spirentcom.com/analysis/product_line.cfm?wt=2&az-c=pl&PL=33

Lightpointe was the first company tested because they were local and they were available to assist in the baseline testing. The personnel from Lightpointe that assisted in this field test were Jim McGowen, Director of Sales; and Albert Borquez, Senior Network Engineer. The product Lightpointe brought was the FlightStrata-155M. The baseline testing was conducted to ensure that the local area networks were operating correctly and to ensure the logistical items (tent, remote power, power on the roof of Raytheon, etc…) were in place. Many factors, including weather and distance, initially challenged this testing evolution. The testing conducted on the first day, 2 February, was limited. The table below represents two SolarWinds raw data points which were taken late into the night (Table 21).

Baseline testing (FSO - Lightpointe)				
Run No.	**Media**	**Size**	**Throughput**	**VOICE**
1	FSO	300 M	61M	NO
Voice and Data				
2	FSO	30 M	27M	YES

Table 21. FSO BASELINE AT RAYTHEON

In addition to the data monitored by SolarWinds, raw data points were taken using Iperf. Iperf is a bandwidth measuring tool used to measure end-to-end bandwidth by using Transport Control Protocol (TCP) streams.[44] The raw data below represents some Iperf measurements taken on February 2:

```
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  8.0 KByte (default)
------------------------------------------------------------
[108] local 192.168.1.2 port 5001 connected with 192.168.3.3 port 1054
[ ID] Interval          Transfer        Bandwidth
[108]  0.0-20.0 sec     89.7 MBytes     35.8 Mbits/sec
[928] 15.0-20.2 sec     864 KBytes       1.3 Mbits/sec
[928]  0.0-21.1 sec     3.5 Mbytes       1.3 Mbits/sec
```

[44] Ajay Tirumala, Les Cottrell, Tom Dunigan: "Measuring end-to-end bandwidth using Iperf using Web 100" *under Iperf folder

Looking at the throughput summary data provided by SmartBits (Table 22, below), it is clear to see the frame loss. The table shows the frame size measured in Mbytes, the throughput percentage max load shows the amount of data being processed across the link (measured in Mbytes), and the frame loss shows the percentage of packets lost in transition between the two chassis. The frame loss measured in this run resulted from operating in the rain and in the dark over a large distance. This testing was conducted around 2000 hours under rainy conditions.

FrameSize	128	192	256	320	384	448	512	576
Throughput (% max load)	10	10	10	10	10	10	10	10
Frame Loss (%)	0.07	1.33	0.86	0	29.6	0	0	0
FrameSize	640	704	768	832	896	960	1024	1088
Throughput (% max load)	10	10	10	10	20	10	20	10
Frame Loss (%)	1.93	0	21.2	4.01	0	8.79	0	5.88
FrameSize	1152	1216	1280	1344	1408	1472		
Throughput (% max load)	10	10	20	10	10	10		
Frame Loss (%)	6.45	0	0	16.6	0	0		

Table 22. SMARTBITS RAYTHEON BASELINE TESTING

The figure below is a product of SmartBits. The figure gives a graphical representation of throughput versus frame loss (Figure 35).

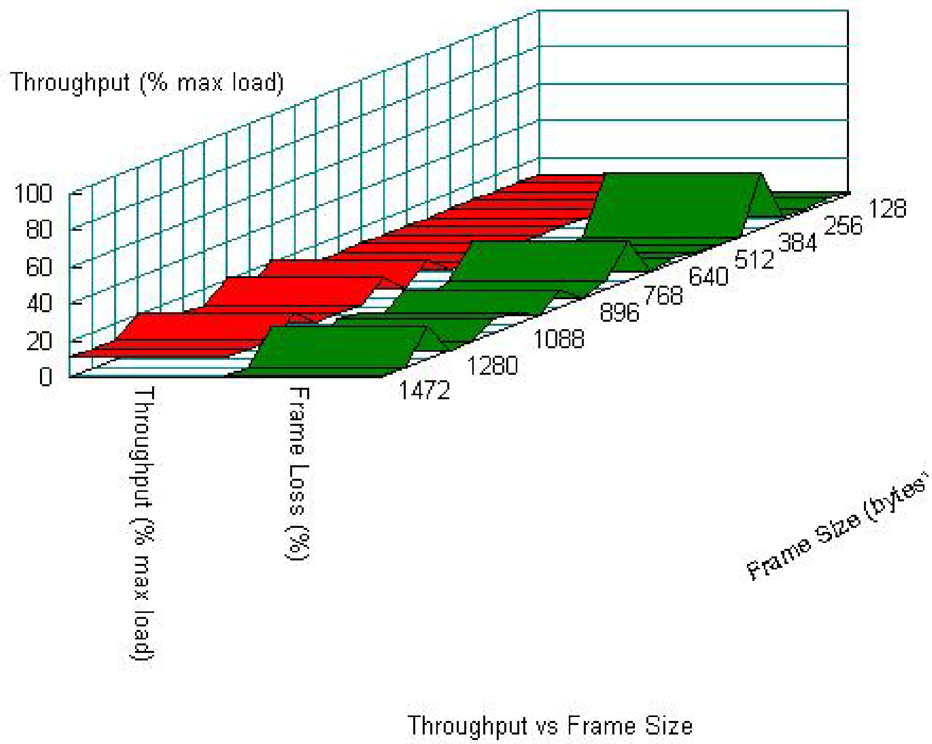

Figure 36. SMARTBITS RAYTHEON BASELINE GRAPHICS

On 3 February, connectivity between the two sites was again established with Lightpointe's product. The weather was hazy with light rain. The SolarWinds data taken was a measure of data files (Power Point, Word documents, Excel, and Adobe documents) being transferred from one LAN to another LAN. The following data was obtained using SolarWinds (Table 23).

CAC2S to CAC2S LIGHTPOINTE 6.7km							
Run No.	**Media**	**Size**	**Time**	**Throughput**	**Loss (%)**	**VOICE**	**VIDEO**
1	FSO	1.5 M	1"	2.2M	0	NO	NO
2	FSO	5 M	7"	7M	0	NO	NO
3	FSO	10 M	2"	14M	0	NO	NO
4	FSO	Iperf		40M	0	NO	NO
5	FSO	75 M	15"	35M	0	NO	NO
6	FSO	150 M	42"	38M	0	NO	NO
7	FSO	300 M	1'24"	36M	0	NO	NO
8	FSO	600 M	2'30"	38M	0	NO	NO
9	FSO	1.2 GIG	5'30"	37M	0	NO	NO

Table 23. LIGHTPOINTE AT RAYTHEON

The following Iperf data points were taken immediately following the SolarWinds data:

```
------------------------------------------------------------
Client connecting to 192.168.1.2, TCP port 5001
TCP window size: 63.0 KByte (default)
------------------------------------------------------------
[928] local 192.168.3.3 port 1054 connected with 192.168.1.2 port 5001
[ ID] Interval       Transfer     Bandwidth
[928]  0.0- 5.0 sec  22.8 MBytes  36.5 Mbits/sec
[928]  5.0-10.0 sec  22.8 MBytes  36.5 Mbits/sec
[928] 10.0-15.0 sec  21.5 MBytes  34.3 Mbits/sec
[928] 15.0-20.0 sec  22.6 MBytes  36.1 Mbits/sec
[928]  0.0-20.0 sec  89.7 MBytes  35.8 Mbits/sec.
```

The data below describes the load, throughput, packets sent, packets received, packets lost, and the percent of lost packets. A throughput summary of the detailed data produced by SmartBits is as follows (Table 24).

Name	Load (%)	Throughput	Sent	Received	Lost	Loss (%)
Total	10	10	16200	16198	2	0.01235
Data Group	N/A	10	16200	16198	2	0.01235
Total	20	20	32500	32500	0	0
Data Group	N/A	20	32500	32500	0	0
Total	30	20	48700	35389	13311	27.3327
Data Group	N/A	20	48700	35389	13311	27.3327

Table 24. LIGHTPOINTE'S SMARTBITS DATA AT RAYTHEON

An example of a portion of a detailed data run for Lightpointe is demonstrated in Table 25 below. This table demonstrates how data is simulated across the network. One port on Data One sends data to fifty different ports on Data Two. In return a port on Data Two sends data to fifty ports on Data One. The example in Table 25 shows a transfer of data. This system has the capability to simulate data, voice, and video as well.

Name	Frame Size	Load (%)	Throughput	Sent	Received	Lost	Loss (%)
Total		10	10	16200	16198	2	0.01235
Data Group		N/A	10	16200	16198	2	0.01235
Data 1:1-1->2:1-1-0	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-1	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-2	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-3	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-4	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-5	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-6	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-7	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-8	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-9	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-10	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-11	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-12	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-13	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-14	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-15	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-16	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-17	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-18	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-19	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-20	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-21	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-22	1518	0.2	10	162	162	0	0
Data 1:1-1->2:1-1-23	1518	0.2	10	162	161	1	0.61728
Data 1:1-1->2:1-1-24	1518	0.2	10	162	161	1	0.61728
Data 1:1-1->2:1-1-25	1518	0.2	10	162	162	0	0

Table 25. PORTION OF LIGHTPOINTE DATA RUN AT RAYTHEON

Figure 36 is a graphic product of SmartBits. The graphic visually shows the throughput and frame loss of the infrastructure. The visual representation clearly shows a frame size of 1,518 Kbytes with a throughput of 20 Mbps.

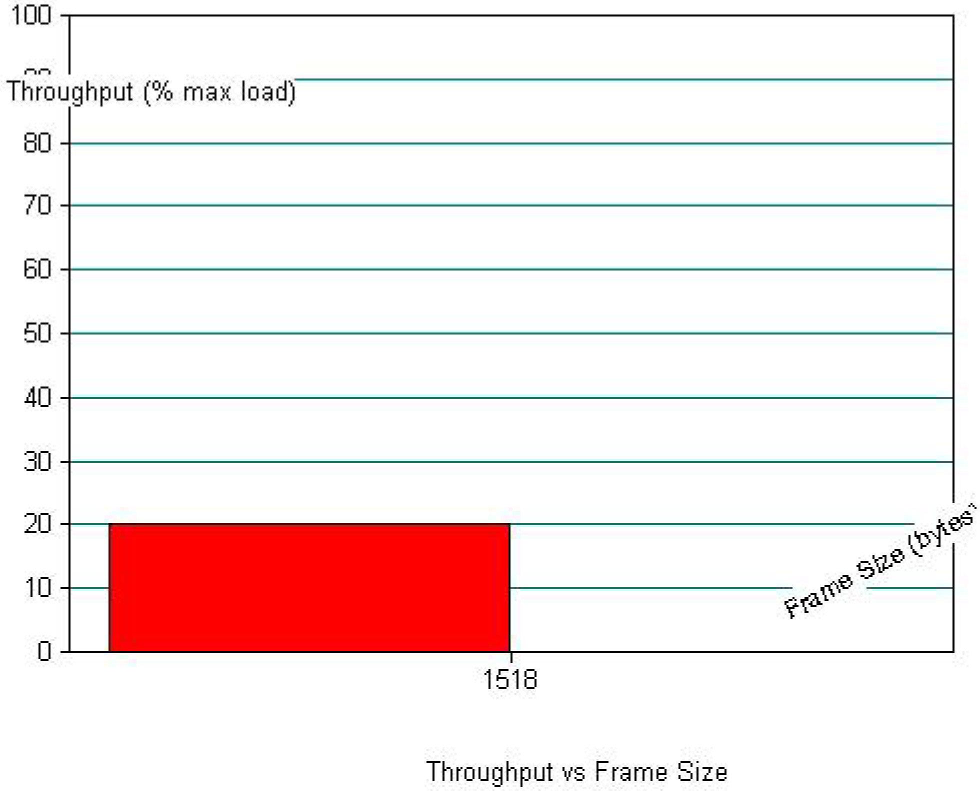

Figure 37. LIGHTPOINTE THROUGHPUT VERSUS FRAME SIZE AT RAYTHEON

b. SecNet-11

Testing of an 802.11b technology (SecNet-11) was conducted on February 2-3, 2004. The configuration was the same as described in Field Test Two. The testing was conducted at a range of 6.7 kilometers. Each bridge was encrypted with a SecNet-11 card. One side of the bridge was connected to the parabolic antenna and the other side of the bridge was connected the network. The special connectors interfacing the bridge and the parabolic antenna and the speed of the ports of the routers and the switches described in Field Test Two apply in the configuration of this experiment. The channel setting for the bridge was channel eleven.

It was raining on 2 February, the night of the baseline testing. Due to the late start, data collected on this day was limited. There were only three data points collected using SolarWinds and one Iperf data point was collected. The table below (Table 26) shows the data collected on February 2-3 from the transfer data test monitored by SolarWinds. On the fourth run, the Iperf test was done in conjunction with the transfer data test.

Baseline testing (802.11b)							
Run No.	**Media**	**Size**	**Time**	**Throughput**	**From**	**To**	**VOICE**
1	802.11b	10 M		1.54M	3.3	1.2	NO
2	802.11b	25 M	3'00"	1.55M	3.3	1.2	NO
3	802.11b	126M		1.62M	3.3	1.2	NO
Second day of testing							
5	802.11b	1.5 M	26"	540k	3.3	1.2	YES

Table 26. SECNET 11 SOLARWINDS DATA FEBRUARY 2-3

The Iperf data was collected prior to securing for the night on 2 February. The following represents the Iperf data collected:

```
------------------------------------------------------------
Client connecting to 192.168.1.3, TCP port 5001
TCP window size: 63.0 KByte (default)
------------------------------------------------------------
[928] local 192.168.3.3 port 1033 connected with 192.168.1.3 port 5001
[ ID]   Interval          Transfer        Bandwidth
[928]  0.0- 5.0 sec       688 KBytes      1.1 Mbits/sec
[928]  5.0-10.0 sec       1.0 MBytes      1.6 Mbits/sec
[928]  10.0-15.0 sec      960 KBytes      1.5 Mbits/sec
[928]  15.0-20.2 sec      864 KBytes      1.3 Mbits/sec
[928]   0.0-21.1 sec      3.5 MBytes      1.3 Mbits/sec
```

On 3 February, the wind was blowing at roughly 15 knots. The first couple of hours were spent erecting the tent and securing the antennas at the remote site. The antenna at the remote site was tied off with a guy wire that was then secured into the ground using tent stakes. The parabolic antenna at the remote site was very stable and did not move, but keeping the parabolic antenna stable on the roof of the Raytheon building was a challenge. The antenna was eventually secured by having an individual hold the antenna in the direction of the remote site. The data table above (Table 26) shows the only data point taken using SolarWinds. The following Iperf data runs indicate lower throughput mainly because of the wind conditions. According to the Certified Wireless Network Administrator Official Study Guide, "Wind does not affect radio waves or an RF signal, but it can affect the positioning and mounting of outdoor antennas….A strong wind could easily move one or both antennas enough to completely degrade the signal between the two antennas. This effect is called 'antenna wind loading.'"[45] The figure below shows an example of antenna wind loading (Figure 37).

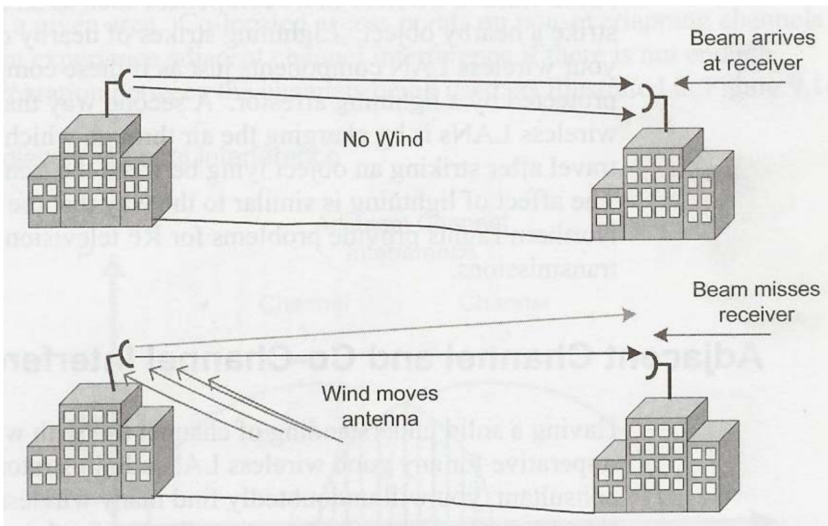

Figure 38. ANTENNA WIND LOADING[46]

Only two runs were conducted due to the bad wind conditions. In comparison to the night before when the wind was not as strong, the throughput was considerably less on the windy day. The following represents the data obtained from the Iperf test:

```
------------------------------------------------------------
Client connecting to 192.168.1.2, TCP port 5001
TCP window size: 63.0 KByte (default)
------------------------------------------------------------
[928] local 192.168.3.3 port 1113 connected with 192.168.1.2 port 5001
[ ID] Interval       Transfer     Bandwidth
[928]  0.0-14.2 sec   72.0 KBytes    40.5 Kbits/sec
```

[45] McGraw-Hill/Osborne, "Certified Wireless Network Administrator Official Study Guide (Exam PW0-100) Second Edition", (Berkeley, California: Planet3 Wireless, Inc. 2003), pg 357.

[46] Ibid McGraw-Hill/Osborne, "Certified Wireless Network Administrator Official Study Guide (Exam PW0-100) Second Edition", (Berkeley, California: Planet3 Wireless, Inc. 2003), pg 357.

```
[928] 14.2-14.2 sec     8.0 KBytes      Inf s/sec
[928] 14.2-15.1 sec    24.0 KBytes      228 Kbits/sec
[928] 15.1-20.0 sec     160 KBytes      258 Kbits/sec
[928]  0.0-20.8 sec     264 KBytes      101 Kbits/sec
```

```
SECOND RUN
------------------------------------------------------------
Client connecting to 192.168.1.2, TCP port 5001
TCP window size: 63.0 KByte (default)
------------------------------------------------------------
[928] local 192.168.3.3 port 1114 connected with 192.168.1.2 port 5001
[ ID] Interval       Transfer     Bandwidth
[928]  0.0- 5.2 sec   360 KBytes   549 Kbits/sec
[928]  5.2-10.1 sec   280 KBytes   464 Kbits/sec
[928] 10.1-15.3 sec   320 KBytes   486 Kbits/sec
[928] 15.3-20.1 sec   272 KBytes   460 Kbits/sec
[928]  0.0-33.8 sec   1.2 MBytes   292 Kbits/sec
```

On the following day a different technology, 802.16, was tested along with FSO. The 802.16 company was Ensemble Communications and the FSO company was Terabeam. This testing is explained in the next two section of this thesis.

c. Ensemble

Ensemble Communications brought equipment that utilizes 802.16 technology. As described earlier in this thesis, 802.16 technology is used for WANs. In the commercial sector, 802.16 is used for backhaul broadband wireless connectivity for many service providers. The personnel who supported this evolution were Jeff Nightingale, Sales Director; Corey Koberg, Engineer; and Jerry Shirey, Field Technician. As discussed in the General Dynamics exercise, Field Test Two, Ensemble's system was ATM based which means that special configurations for both local area networks needed to take place prior to any testing. At the Mobile Research Facility, a single port ATM OC-3 Single-mode Intermediate Reach NM card for the Cisco 3745 router was configured for the router. The 16200 Hub Station was connected to the port on this card with a single-mode fiber cable. At the remote site, the 320 Multiplexer was connected to the remote Cisco 3745 router with CAT-5 cable. Similar to Field Test Two, a Fiberless 282 Series ODU was utilized for the antenna.

The series of tests that were conducted with Ensemble started with Iperf testing, followed by SolarWinds testing, and concluded with SmartBits testing. The Iperf testing was conducted after the two ends were configured to handle an ATM based network. The Iperf data is represented below:

```
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  0.1 MByte
------------------------------------------------------------
[920] local 192.168.3.3 port 5001 connected with 192.168.1.2 port 1038
[ ID] Interval          Transfer       Bandwidth
[920]  0.0- 1.0 sec     2.4 MBytes     19.4 Mbits/sec
[920]  1.0- 2.0 sec     2.8 MBytes     22.7 Mbits/sec
[920]  2.0- 3.0 sec     3.0 MBytes     24.0 Mbits/sec
[920]  3.0- 4.0 sec     3.1 MBytes     24.6 Mbits/sec
[920]  4.0- 5.0 sec     3.2 MBytes     25.5 Mbits/sec
[920]  5.0- 6.0 sec     4.0 MBytes     32.1 Mbits/sec
[920]  6.0- 7.0 sec     4.5 MBytes     35.9 Mbits/sec
[920]  7.0- 8.0 sec     4.5 MBytes     35.9 Mbits/sec
[920]  8.0- 9.0 sec     4.5 MBytes     35.9 Mbits/sec
[920]  9.0-10.0 sec     4.5 MBytes     35.9 Mbits/sec
[920]  0.0-10.0 sec     36.5 MBytes    29.2 Mbits/sec


------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  0.1 MByte
------------------------------------------------------------
[920] local 192.168.3.3 port 5001 connected with 192.168.1.2 port 1041
[ ID] Interval          Transfer       Bandwidth
[920]  0.0- 1.0 sec     3.3 MBytes     26.2 Mbits/sec
[920]  1.0- 2.0 sec     4.5 MBytes     36.0 Mbits/sec
[920]  2.0- 3.0 sec     4.5 MBytes     35.9 Mbits/sec
[920]  3.0- 4.0 sec     3.9 MBytes     30.8 Mbits/sec
[920]  4.0- 5.0 sec     3.1 MBytes     24.5 Mbits/sec
[920]  5.0- 6.0 sec     3.1 MBytes     24.2 Mbits/sec
[920]  6.0- 7.0 sec     3.1 MBytes     25.7 Mbits/sec
[920]  7.0- 8.0 sec     3.2 MBytes     25.6 Mbits/sec
[920]  8.0- 9.0 sec     3.4 MBytes     27.3 Mbits/sec
[920]  9.0-10.0 sec     3.7 MBytes     29.9 Mbits/sec
[920]  0.0-10.0 sec     35.9 MBytes    28.6 Mbits/sec
```

The Iperf data for the first run indicated an average throughput of 29.2 Mbps between the two sites at a distance of 6.7 kilometers. The Iperf data for the second run indicated a throughput of 28.6 Mbps between sites.

The measurements observed using SolarWinds differ from the readings indicated by Iperf. The disparity is due to the type of data that is sent across the link. In the Iperf test, the size of the data being transferred is a consistent steady stream of data going across the network. In the transfer data test monitored by SolarWinds, the data going across the network differs in size of the file and the type of data. The SolarWinds results are represented below (Table 27).

CAC2S to CAC2S ENSEMBLE 6.7km							
Run No.	**Media**	**Size**	**Time**	**Throughput**	**Packet Loss (%)**	**VOICE**	**VIDEO**
1	802.16	1.5 M	1"	2.2M	0	NO	NO
2	802.16	5 M	8"	6.28M	0	NO	NO
3	802.16	10 M	13"	7.84M	0	NO	NO
5	802.16	75 M	1'20"	7.9M	0	NO	NO
6	802.16	150 M	3'00"	7M	0	NO	NO
VOICE, DATA, AND VIDEO							
7	802.16	video		6.46M	0	YES	YES
8	802.16	video		3M	0	YES	YES
9	802.16	video both	sides	6M	0	YES	YES
10	802.16	video	and 75M	7M	0	YES	YES

Table 27. ENSEMBLE RAW SOLARWINDS DATA AT RAYTHEON

The data obtained using SmartBits resembles the data obtained from using Iperf. Four different runs were tested using SmartBits. The first run was to observe where the maximum throughput was located. The second run was to determine where SolarWinds was dropping the link (SolarWinds would indicate the link was not established, however, the link was still up because we were able to use VoIP). The third run was to measure the amount of packet loss when the throughput was doubled. The fourth run was to examine the link with an over-saturation of data.

The maximum throughput was located in a range of 20-30 Mbps, similar to what Iperf produced. The data table below shows an excerpt of the data obtained from the SmartBits program in the first run (Table 28).

FIRST RUN	Load (%)	Throughput	Sent	Received	Lost	Loss (%)
Total	10	10	16218	16218	0	0
Data Group	N/A	10	15900	15900	0	0
TEST Group	N/A	10	318	318	0	0
Total	20	20	32436	32433	3	0.00925
Data Group	N/A	20	31800	31797	3	0.00943
TEST Group	N/A	20	636	636	0	0
Total	30	20	48756	37589	11167	22.90385
Data Group	N/A	20	47800	36867	10933	22.87238
TEST Group	N/A	20	956	722	234	24.47699
FrameSize	1518					
Throughput (% max load)	20					
Frame Loss (%)	0.00925					

Table 28. ENSEMBLE SMART BITS DATA AT RAYTHEON

The figure below shows a graphic representation of the throughput of SmartBits. This graphic representation indicates there was no packet loss in the above test when the load was at 20 Mbps (Figure 38).

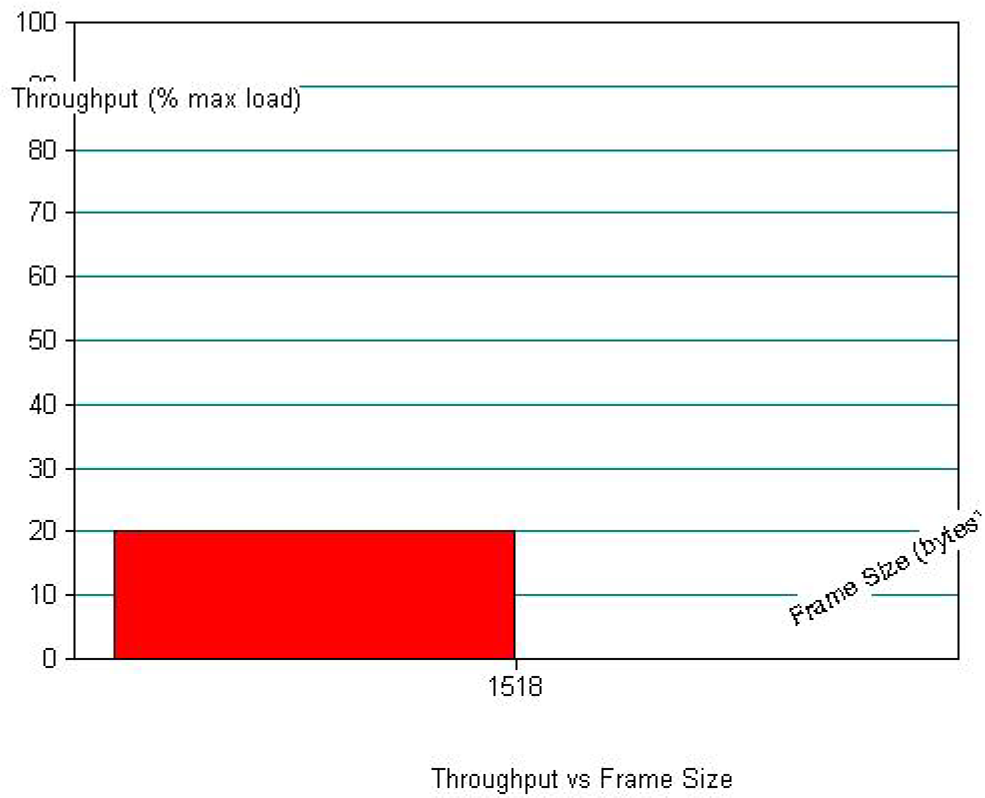

Figure 39. ENSEMBLE SMART BITS GRAPHICS AT RAYTHEON

The third run using Smart Bits was an experiment to determine the amount of packet loss if the throughput load was doubled. The data indicated that when the throughput was doubled (the amount of data being sent was two times the size of the 20-30 Mbps throughput being allowed by Ensemble's equipment), the packet loss increased. The table below indicates the results obtained on the third run (Table 29).

THIRD RUN	Load (%)	Throughput	Sent	Received	Lost	Loss (%)
Total	10	10	16218	16218	0	0
Data Group	N/A	10	15900	15900	0	0
TEST Group	N/A	10	318	318	0	0
Total	20	20	32436	32435	1	0.00308
Data Group	N/A	20	31800	31799	1	0.00314
TEST Group	N/A	20	636	636	0	0
Total	30	30	48756	37587	11169	22.90795
Data Group	N/A	30	47800	36841	10959	22.92678
TEST Group	N/A	30	956	746	210	21.96653
Total	40	40	64974	37571	27403	42.17533
Data Group	N/A	40	63700	36814	26886	42.20722
TEST Group	N/A	40	1274	757	517	40.58085
Total	50	40	81192	37556	43636	53.74421
Data Group	N/A	40	79600	36908	42692	53.63317
TEST Group	N/A	40	1592	648	944	59.29648

FrameSize	1518
Throughput (% max load)	40
Frame Loss (%)	42.17533

Table 29. ENSEMBLE SMARTBITS DATA (X2) AT RAYTHEON

The graphic illustration below compares the throughput and the frame loss during the third run (Figure 39).

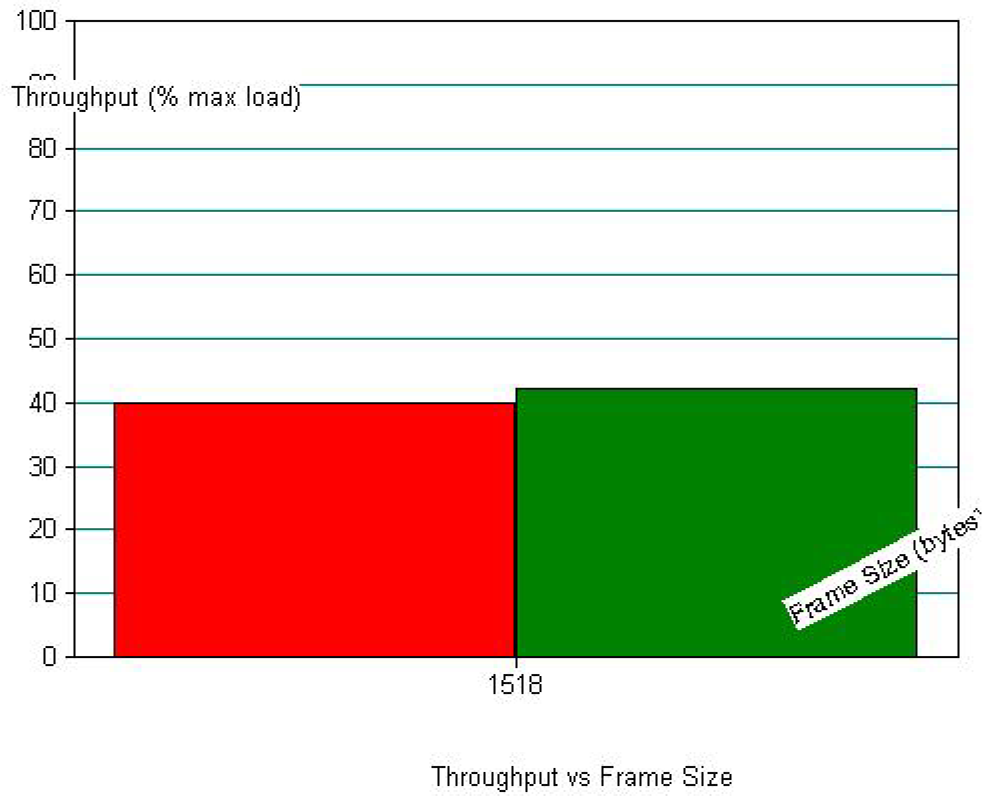

Figure 40. ENSEMBLE PACKET LOSS AT RAYTHEON

The second run will be covered in the Findings and Analysis portion of the thesis because these runs focused on why the link dropped out between the 30 to 40 Mbps phase of the experiment. The fourth run will be covered in the Findings and Analysis portion also because the data is similar to the results obtained in the third run (saturation of the network). The third run indicated that when the network is oversaturated, then an increase of packet loss is observed. This is to say that there is an upper limit of data that can be processed by the medium providing the link between the networks. Once this upper limit is reached then the network will experience packet loss.

FSO was also tested on the same day. The name of the company tested was Terabeam from Redmond, Washington.

d. Terabeam

Terabeam produces FSO equipment as well as Radio Frequency (RF) equipment. Their RF product is a 60 GHz millimeter wave (MMW) system. The FSO product that was brought was the Elliptica. The difference between this company and the other companies is that Terabeam's product uses only one laser at the 1550 nanometer wavelength. Other impressive features of the Elliptica are the optical scope, the auto tracking feature, and the easy setup. The optical scope was used to align the two lasers. The alignment process took a total of 5 minutes. The auto-tracking feature compensates for the swaying of buildings or the movement of the distant laser. The setup of the Elliptica was done quickly and efficiently. The Elliptica comes with deployable mounts used to set the optical head (Figure 40).

Figure 41. TERABEAM ELLIPTICA

The Terabeam personnel who supported the Raytheon Testing were Pascal Boudreau, Eric Ruberg, and Carrie Cornish. Their level of expertise and professionalism shined throughout the testing evolution.

Similar to the other products tested, Terabeam followed the same series of tests. The series of tests consisted of taking data from an Iperf test, a file transfer test (SolarWinds data), and a SmartBits test. When the Iperf test was conducted, setting the window size of the data being transferred was very important. If the window size was too low, the data throughput would result in a lower value. An example of this is demonstrated in the Findings and Analysis portion of the thesis. The Iperf data obtained on Terabeam was one of the highest obtained at Raytheon. The data below represents the Iperf data taken on Terabeam:

```
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  0.1 MByte
------------------------------------------------------------
[920] local 192.168.3.3 port 5001 connected with 192.168.1.2 port 1059
[ ID] Interval        Transfer      Bandwidth
[920]  0.0- 1.0 sec    8.7 MBytes    69.7 Mbits/sec
[920]  1.0- 2.0 sec    9.8 MBytes    78.4 Mbits/sec
[920]  2.0- 3.0 sec    9.7 MBytes    77.4 Mbits/sec
[920]  3.0- 4.0 sec    10.7 MBytes   85.3 Mbits/sec
[920]  4.0- 5.0 sec    10.2 MBytes   81.3 Mbits/sec
[920]  5.0- 6.0 sec    9.5 MBytes    76.3 Mbits/sec
[920]  6.0- 7.0 sec    10.9 MBytes   88.3 Mbits/sec
[920]  7.0- 8.0 sec    10.9 MBytes   87.2 Mbits/sec
[920]  8.0- 9.0 sec    11.3 MBytes   90.2 Mbits/sec
[920]  9.0-10.0 sec    10.9 MBytes   87.0 Mbits/sec
[920]  0.0-10.0 sec    10.3 MBytes   82.1 Mbits/sec
```

The next series of testing involved the transfer of data files that would be found on the battlefield. These files include Power Point, Excel, Word, Adobe, and basic text files being transferred from one computer in one local area network to another computer in another local area network. SolarWinds was used to monitor the data transfer. There were nine different runs conducted during this data testing evolution. The first seven runs were simple data transfer between the two local area networks measuring throughput and time for the data to be transferred. The next series of data runs, VoIP and video programs were running on the computers while executing the data file transfer test. The purpose of these runs was to see if other applications had an effect on the throughput of the data being transferred. The result was that there was no loss in audio quality in the VoIP and no loss in the video quality of the videos being played on the computers during the transfer. The data below represents the data transfer from one local area network to the other local area network via Terabeam's link (Table 30).

CAC2S to CAC2S							
TERABEAM		6.7km					
Run No.	**Media**	**Size**	**Time**	**Throughput**	**Packet Loss (%)**	**VOICE**	**VIDEO**
1	FSO	1.5 M	1"	2.2M	0	NO	NO
2	FSO	5 M	6"	7.29M	0	NO	NO
3	FSO	10 M	2"	14M	0	NO	NO
4	FSO	25 M	1"	18M	0	NO	NO
5	FSO	75 M	1'08"	24M	0	NO	NO
6	FSO	150 M	1'12"	35M	0	NO	NO
7	FSO	300 M	3'56"	36M	0	NO	NO
VOICE, DATA, AND VIDEO							
8	FSO	5M		6M	0	YES	YES
9	FSO	5M		6M	0	YES	YES

Table 30. TERABEAM’S SOLAR WIND DATA AT RAYTHEON

There were two runs using SmartBits for the Terabeam product. The first run was conducted to measure the data transfer between the two LANs. The data is represented below (Table 31).

Name	Load (%)	Throughput	Sent	Received	Lost	Loss (%)
Total	10	10	16218	16210	8	0.04933
Data Group	N/A	10	15900	15892	8	0.05031
Smart Bit Group	N/A	10	318	318	0	0
Total	20	20	32436	32433	3	0.00925
Data Group	N/A	20	31800	31797	3	0.00943
Smart Bit Group	N/A	20	636	636	0	0
Total	30	30	48756	48740	16	0.03282
Data Group	N/A	30	47800	47784	16	0.03347
Smart Bit Group	N/A	30	956	956	0	0
Total	40	40	64974	64963	11	0.01693
Data Group	N/A	40	63700	63690	10	0.0157
Smart Bit Group	N/A	40	1274	1273	1	0.07849
Total	50	50	81192	81169	23	0.02833
Data Group	N/A	50	79600	79579	21	0.02638
Smart Bit Group	N/A	50	1592	1590	2	0.12563
Total	60	60	97512	97486	26	0.02666
Data Group	N/A	60	95600	95576	24	0.0251
Smart Bit Group	N/A	60	1912	1910	2	0.1046
Total	70	70	113730	113652	78	0.06858
Data Group	N/A	70	111500	111424	76	0.06816
Smart Bit Group	N/A	70	2230	2228	2	0.08969
Total	80	80	129948	129877	71	0.05464
Data Group	N/A	80	127400	127329	71	0.05573
Smart Bit Group	N/A	80	2548	2548	0	0
Total	90	90	146268	146174	94	0.06427
Data Group	N/A	90	143400	143309	91	0.06346
Smart Bit Group	N/A	90	2868	2865	3	0.1046
Total	100	100	162486	161946	540	0.33234
Data Group	N/A	100	159300	158764	536	0.33647
Smart Bit Group	N/A	100	3186	3182	4	0.12555
FrameSize	1518					
Throughput (% max load)	100					
Frame Loss (%)	0.33234					

Table 31. TERABEAM'S SMART BITS DATA TRANSFER

The graphical representation shown below is a graph of throughput versus frame size (Figure 41).

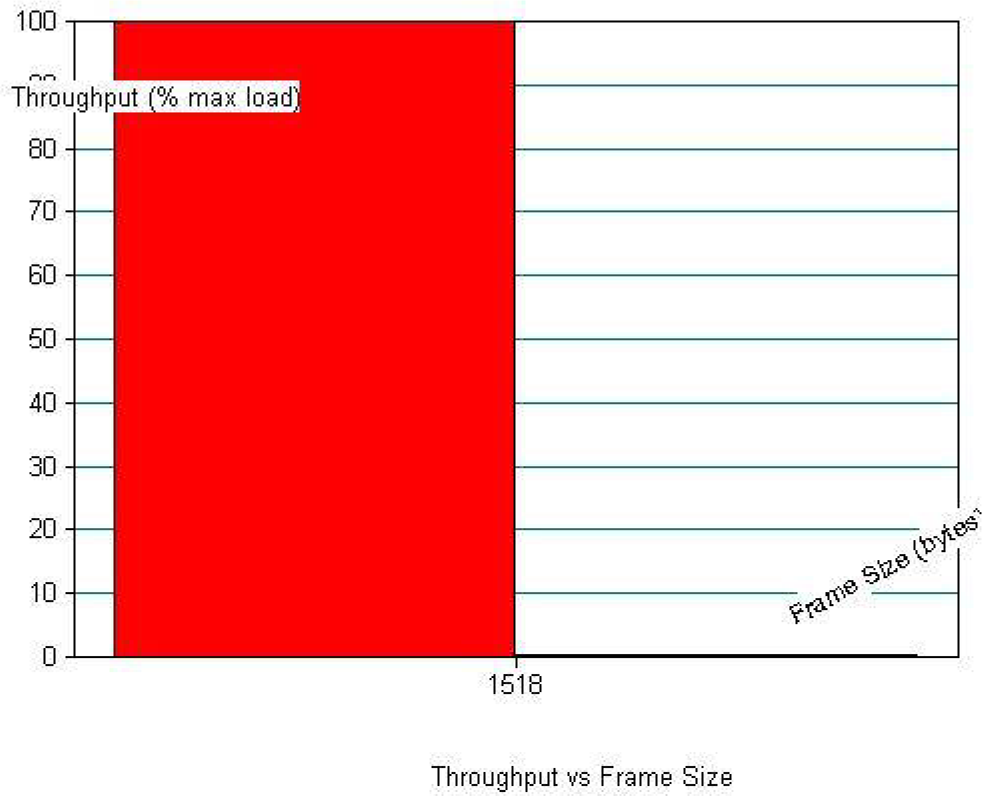

Figure 42. TERABEAM GRAPHICAL DATA REPRESENTATION

The next run of testing included the VoIP function of SmartBits. The SmartBits equipment generated data packets along with VoIP packets across the Terabeam link. The data below represents the SmartBits data obtained while employing the VoIP function with Terabeam's link (Table 32).

Name	Load (%)	Throughput	Sent	Received	Lost	Loss (%)
Total	10	10	16224	16221	3	0.01849
Data Group	N/A	10	15600	15597	3	0.01923
Smart Bit Group	N/A	10	312	312	0	0
VoIP Group	N/A	10	312	312	0	0
Total	20	20	32448	32435	13	0.04006
Data Group	N/A	20	31200	31187	13	0.04167
Smart Bit Group	N/A	20	624	624	0	0
VoIP Group	N/A	20	624	624	0	0
Total	30	30	48672	48657	15	0.03082
Data Group	N/A	30	46800	46785	15	0.03205
Smart Bit Group	N/A	30	936	936	0	0
VoIP Group	N/A	30	936	936	0	0
Total	40	40	65000	64990	10	0.01538
Data Group	N/A	40	62500	62490	10	0.016
Smart Bit Group	N/A	40	1250	1250	0	0
VoIP Group	N/A	40	1250	1250	0	0
Total	50	50	81224	81199	25	0.03078
Data Group	N/A	50	78100	78077	23	0.02945
Smart Bit Group	N/A	50	1562	1561	1	0.06402
VoIP Group	N/A	50	1562	1561	1	0.06402
Total	60	60	97448	97425	23	0.0236
Data Group	N/A	60	93700	93677	23	0.02455
Smart Bit Group	N/A	60	1874	1874	0	0
VoIP Group	N/A	60	1874	1874	0	0
Total	70	70	113776	113683	93	0.08174
Data Group	N/A	70	109400	109308	92	0.0841
Smart Bit Group	N/A	70	2188	2187	1	0.0457
VoIP Group	N/A	70	2188	2188	0	0
Total	80	80	130000	129940	60	0.04615
Data Group	N/A	80	125000	124942	58	0.0464
Smart Bit Group	N/A	80	2500	2498	2	0.08
VoIP Group	N/A	80	2500	2500	0	0
Total	90	90	146224	146143	81	0.05539
Data Group	N/A	90	140600	140525	75	0.05334
Smart Bit Group	N/A	90	2812	2808	4	0.14225
VoIP Group	N/A	90	2812	2810	2	0.07112
Total	100	100	162448	161850	598	0.36812
Data Group	N/A	100	156200	155618	582	0.3726
Smart Bit Group	N/A	100	3124	3118	6	0.19206
VoIP Group	N/A	100	3124	3114	10	0.3201

FrameSize	1518
Throughput (% max load)	100
Frame Loss (%)	0.36812

Table 32. TERABEAM VOIP SMART BITS DATA AT RAYTHEON

Terabeam was used to test the KG- 235s. The KG- 235 is a bulk INE that is used to secure the link between the two sites. The KG-235 was placed into the network as described in the previous testing at General Dynamics.

e. Crypto (INE)

The placement of the In-Line Encryptor (INE) was between the Terabeam link and the local area network's Cisco 3550 switch. The Cisco 3745 routers were removed from the network in order to make the KG-235s work properly. The KG-235s functioned as routers for the two networks. The KG-235s were assigned Internet Protocol network addresses on different subnets in order for the two networks to communicate with each other. A CAT-5 cable was used to connect one side (one of two Ethernet ports on the KG-235) to the Elliptica from Terabeam. The other side (second Ethernet port) of the KG-235 was connected to the local area network's Cisco 3550 switch with CAT-5 cable. The laptops, configured on the same subnet as the KG-235, were connected to the switch.

Two runs were conducted using the Iperf test. The first run was conducted with max window size set for the computers to handle maximum throughput across the link. The data below represents the first run of data.

```
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  0.1 MByte
------------------------------------------------------------
[920] local 192.168.3.3 port 5001 connected with 192.168.1.2 port 1072
[ ID] Interval          Transfer        Bandwidth
[920]  0.0- 1.0 sec     0.6 MBytes      4.4 Mbits/sec
[920]  1.0- 2.0 sec     0.5 MBytes      4.0 Mbits/sec
[920]  2.0- 3.0 sec     0.6 MBytes      4.4 Mbits/sec
[920]  3.0- 4.0 sec     0.5 MBytes      4.1 Mbits/sec
[920]  4.0- 5.0 sec     0.5 MBytes      4.4 Mbits/sec
[920]  5.0- 6.0 sec     0.4 MBytes      3.4 Mbits/sec
[920]  6.0- 7.0 sec     0.5 MBytes      4.4 Mbits/sec
[920]  7.0- 8.0 sec     0.5 MBytes      3.7 Mbits/sec
[920]  8.0- 9.0 sec     0.5 MBytes      4.3 Mbits/sec
[920]  9.0-10.0 sec     0.4 MBytes      3.4 Mbits/sec
[920]  0.0-10.1 sec     5.1 MBytes      4.1 Mbits/sec
```

During the second run the settings on the INE itself were maximized to full capacity and the following results were achieved:

```
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  0.1 MByte
------------------------------------------------------------
[920] local 192.168.3.3 port 5001 connected with 192.168.1.2 port 1036
[ ID] Interval          Transfer       Bandwidth
[920]  0.0- 1.3 sec     0.1 MBytes     0.8 Mbits/sec
[920]  1.3- 2.1 sec     0.0 MBytes     0.1 Mbits/sec
[920]  2.1- 3.0 sec     0.5 MBytes     4.0 Mbits/sec
[920]  3.0- 4.0 sec     0.3 MBytes     2.6 Mbits/sec
[920]  4.0- 5.0 sec     0.5 MBytes     4.1 Mbits/sec
[920]  5.0- 6.0 sec     0.5 MBytes     4.2 Mbits/sec
[920]  6.0- 7.0 sec     0.5 MBytes     3.8 Mbits/sec
[920]  7.0- 8.0 sec     0.5 MBytes     4.0 Mbits/sec
[920]  8.0- 9.0 sec     0.5 MBytes     3.9 Mbits/sec
[920]  9.0-10.0 sec     0.5 MBytes     3.9 Mbits/sec
[920]  0.0-10.4 sec     4.0 MBytes     3.1 Mbits/sec
```

It was discovered during the second run that the INE needed the latest firmware in order to provide a larger throughput for the network. This information was not known prior to the experiment, which limited a thorough examination of the INE.

Later in the week, another FSO company named fSONA tested the link with the KG-235s. Here again the window size was manipulated in order to achieve maximum throughput across the link. The maximum throughput obtained using the KG-235 is represented below.

```
Encrypted with KG-235
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  0.1 MByte
------------------------------------------------------------
[920] local 192.168.1.25 port 5001 connected with 192.168.3.25 port 1808
[ ID] Interval          Transfer       Bandwidth
[920]  0.0- 1.0 sec     0.6 Mbytes     4.8 Mbits/sec
[920]  1.0- 2.0 sec     0.6 MBytes     5.0 Mbits/sec
[920]  2.0- 3.0 sec     0.6 MBytes     5.0 Mbits/sec
[920]  3.0- 4.0 sec     0.6 MBytes     5.0 Mbits/sec
[920]  4.0- 5.0 sec     0.6 MBytes     5.0 Mbits/sec
[920]  5.0- 6.0 sec     0.6 MBytes     5.0 Mbits/sec
[920]  6.0- 7.0 sec     0.6 MBytes     5.0 Mbits/sec
```

```
[920]  7.0- 8.0 sec      0.6 MBytes      5.1 Mbits/sec
[920]  8.0- 9.0 sec      0.6 MBytes      4.9 Mbits/sec
[920]  9.0-10.0 sec      0.6 MBytes      5.0 Mbits/sec
[920]  0.0-10.1 sec      6.3 MBytes      5.0 Mbits/sec
```

The following day the authors introduced a new technology to the field-testing site, Radio Frequency Module (RFM).

f. RFM

The RFM, described earlier in the General Dynamics testing portion of the thesis, is produced by Ceragon Networks. GDDS packages the product in a deployable case with a Cisco 2950 switch for GDDS customers. The hardened case and microwave dish is field expedient to withstand a rugged military environment. GDDS supported the experiment with Jon Seime and William Dean.

The series of tests conducted with the RFM involved the RFM conducting an Iperf test, a data transfer test monitored by SolarWinds, and a SmartBits test. After the RFM was tested, MRV's Terescope 3000 (Free Space Optics product) was tested. This testing is described later in the thesis. Immediately following the FSO test, MRV's OptiSwitch was tested. The MRV's OptiSwitch was used in combination with the RFM and the FSO. This testing is described later in the thesis as well.

During the Iperf testing with the RFM, the students conducted several data runs to find the appropriately sized packet that would maximize throughput for data file transfers. The Iperf data below represents the maximum throughput data gathered across the RFM link.

```
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  0.1 MByte
------------------------------------------------------------
[920] local 192.168.3.3 port 5001 connected with 192.168.1.2 port 1090
[ ID] Interval          Transfer         Bandwidth
[920]  0.0- 1.0 sec     11.0 MBytes      88.2 Mbits/sec
[920]  1.0- 2.0 sec     11.1 MBytes      88.6 Mbits/sec
[920]  2.0- 3.0 sec     10.6 MBytes      84.3 Mbits/sec
[920]  3.0- 4.0 sec     10.6 MBytes      85.0 Mbits/sec
[920]  4.0- 5.0 sec     10.6 MBytes      84.9 Mbits/sec
[920]  5.0- 6.0 sec     11.3 MBytes      90.2 Mbits/sec
```

[920]	6.0- 7.0 sec	11.2 MBytes	90.2 Mbits/sec
[920]	7.0- 8.0 sec	11.3 MBytes	90.2 Mbits/sec
[920]	8.0- 9.0 sec	11.3 MBytes	90.2 Mbits/sec
[920]	9.0-10.0 sec	11.3 MBytes	90.2 Mbits/sec
[920]	0.0-10.0 sec	110 MBytes	88.3 Mbits/sec

The transfer of data test monitored by SolarWinds illustrated a maximum throughput of 40 Mbps. During this series of testing, there were 9 runs completed in all. The first run was only a 300 Mbyte data file transferred from one local area network to another. During the data file transfer, VoIP quality was monitored by the clarity of the voice conversation while the transfer was occurring. For the remainder of the data file transfer test, along with VoIP, there was a video camera transmitting data across the link. Additionally, a video file was being played on one of the computers that was transferring data files to the distant end of the network. The data gathered is represented in the table below (Table 33).

CAC2S to CAC2S RFM 6.7km							
Run No.	**Media**	**Size**	**Time**	**Throughput**	**Loss (%)**	**VOICE**	**VIDEO**
VOICE AND DATA							
1	Microwave	300 M	1'15"	40M	0	YES	NO
VOICE, DATA, AND VIDEO							
2	Microwave	1.5 M	1"	2.7M	0	YES	YES
3	Microwave	5 M	2"	7.8M	0	YES	YES
4	Microwave	10 M	5"	15M	0	YES	YES
5	Microwave	75 M	17"	32M	0	YES	YES
6	Microwave	150 M	38"	36M	0	YES	YES
7	Microwave	300 M	1'20"	33M	0	YES	YES
8	Microwave	600 M	3'14"	39M	0	YES	YES
9	Microwave	1.2 GIG	6'30"	36M	0	YES	YES

Table 33. RFM SOLARWINDS DATA AT RAYTHEON

During the SmartBits test, SmartBits simulated 20 VoIP phone conversations going across the network. Additionally, SmartBits simulated 100 computers passing information simultaneously across the network. The test revealed a less than 1 % packet loss across the network as the load on the network increased in 10 Mbyte increments. The table below shows the information gathered during this series of testing (Table 34).

Name	Load (%)	Throughput	Sent	Received	Lost	Loss (%)
Total	10	10	26000	26000	0	0
Data Group	N/A	10	9300	9280	20	0.21505
VoIP Group	N/A	10	13000	13000	0	0
Total	20	20	39000	39000	0	0
Data Group	N/A	20	18600	18560	40	0.21505
VoIP Group	N/A	20	13000	13000	0	0
Total	30	30	52000	52000	0	0
Data Group	N/A	30	27880	27840	40	0.14347
VoIP Group	N/A	30	13000	13000	0	0
Total	40	40	65000	65000	0	0
Data Group	N/A	40	37160	37120	40	0.10764
VoIP Group	N/A	40	13000	13000	0	0
Total	50	50	91000	91000	0	0
Data Group	N/A	50	55720	55700	20	0.03589
VoIP Group	N/A	50	13000	13000	0	0
Total	60	60	104000	104000	0	0
Data Group	N/A	60	65000	65000	0	0
VoIP Group	N/A	60	13000	13000	0	0
Total	70	70	117000	117000	0	0
Data Group	N/A	70	74300	74280	20	0.02692
VoIP Group	N/A	70	13000	13000	0	0
Total	80	80	130000	130000	0	0
Data Group	N/A	80	83600	83560	40	0.04785
VoIP Group	N/A	80	13000	13000	0	0
Total	90	90	156000	156000	0	0
Data Group	N/A	90	102160	102120	40	0.03915
VoIP Group	N/A	90	13000	13000	0	0
Total	100	100	169000	169000	0	0
Data Group	N/A	100	111440	111400	40	0.03589
VoIP Group	N/A	100	13000	13000	0	0

Table 34. RFM SMART BITS DATA AT RAYTHEON

As mentioned earlier in this section, FSO was tested on the same day as the RFM. The FSO company was MRV. Founded in 1988, MRV's corporate headquarters is in Chatsworth, California.[47]

g. MRV

The personnel that supported the evolution were Tim Kcehowski, Director of Federal Sales; Levon Fayson, Technical Support Engineering Manager; and Isaac Kim, Director of FSO. Mr. Fayson diligently set up and aligned the Terescope 5000 OC-

[47] http://archive.mrv.com/corporate/profile.php

3 link heads. The environment was a metropolitan area spanning a distance between sites of 6,700 meters. The weather was very windy with partly sunny skies and a temperature in the mid 60's.

The data collected during MRV's Terescope test involved the Iperf test, the data transfer test monitored by SolarWinds, and the SmartBits test. Several runs of the Iperf test were conducted. The reason for several runs was that the soft rooftop on Raytheon's building, where the Terescope was mounted, and people walking around the Terescope caused enough movement to the scope to take it out of alignment. This will be addressed by MRV adding new advanced tracking into their FSO system. The Terescope was secured with concrete blocks in order to stabilize it on top of the building. The Iperf data below represents the maximum data throughput via MRV's link.

```
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  0.1 MByte
------------------------------------------------------------
[920] local 192.168.3.3 port 5001 connected with 192.168.1.2 port 1063
[ ID] Interval          Transfer      Bandwidth
[920]  0.0- 1.0 sec     11.1 MBytes   88.3 Mbits/sec
[920]  1.0- 2.0 sec     11.2 MBytes   89.8 Mbits/sec
[920]  2.0- 3.0 sec     11.2 MBytes   89.9 Mbits/sec
[920]  3.0- 4.0 sec     11.2 MBytes   89.7 Mbits/sec
[920]  4.0- 5.0 sec     11.3 MBytes   89.9 Mbits/sec
[920]  5.0- 6.0 sec     11.2 MBytes   89.7 Mbits/sec
[920]  6.0- 7.0 sec     11.1 MBytes   89.9 Mbits/sec
[920]  7.0- 8.0 sec     11.3 MBytes   89.9 Mbits/sec
[920]  8.0- 9.0 sec     11.2 MBytes   89.7 Mbits/sec
[920]  9.0-10.0 sec     11.3 MBytes   90.1 Mbits/sec
[920]  0.0-10.0 sec      112 MBytes   89.7 Mbits/sec
```

The data file transfer test monitored by SolarWinds consisted of a total of 18 runs. The first series of runs consisted of data files transferred from one local area network to another. The data files ranged from 1.5 Mbytes to 1.2 Gbytes in size. The second series of runs consisted of data file transfers while VoIP was running as the data files were transferred from one local area network to another. The last series of runs consisted of data files being transferred while VoIP and video were running as the data files were being transferred. The table below represents the data obtained from the data file transfer test using SolarWinds (Table 35).

CAC2S to CAC2S MRV 6.7km							
Run No.	**Media**	**Size**	**Time**	**Throughput**	**Loss (%)**	**VOICE**	**VIDEO**
1	FSO	1.5 M	1"	2.8M	0	NO	NO
2	FSO	5 M	1"	7.92M	0	NO	NO
3	FSO	10 M	2"	15M	0	NO	NO
4	FSO	75 M	15"	50M	0	NO	NO
5	FSO	150 M	33"	46M	0	NO	NO
6	FSO	300 M	1'03"	47M	0	NO	NO
7	FSO	600 M	2'12"	50M	0	NO	NO
8	FSO	1.2 GIG	4'20"	53M	3	NO	NO
VOICE							
9	FSO	1.5 M	1"	6M	0	YES	NO
10	FSO	5 M	1"	8M	0	YES	NO
11	FSO	10 M	2"	15M	0	YES	NO
12	FSO	75 M	16"	59M	0	YES	NO
13	FSO	150 M	32"	50M	0	YES	NO
14	FSO	300 M	59"	50m	0	YES	NO
15	FSO	600 M	2'50"	40m	0	YES	NO
VOICE, DATA, AND VIDEO							
16	FSO	1.5 M	1"	6M	0	YES	YES
17	FSO	5 M	1"	8M	0	YES	YES
18	FSO	10 M	2"	15M	0	YES	YES

Table 35. MRV'S SOLARWINDS DATA AT RAYTHEON

The final test conducted using only MRV's link was a SmartBits test. SmartBits generated simulated data being transferred across the link. The simulated data consisted of 100 computers passing information across the network plus 20 simulated VoIP phone conversations going across the network. The table below is an excerpt of the data obtained from SmartBits (Table 36).

Name	Load (%)	Throughput	Sent	Received	Lost	Loss (%)
Total	10	10	26000	26000	0	0
Data Group	N/A	10	13000	13000	0	0
VoIP Group	N/A	10	13000	13000	0	0
Total	20	20	39000	39000	0	0
Data Group	N/A	20	26000	26000	0	0
VoIP Group	N/A	20	13000	13000	0	0
Total	30	30	52000	52000	0	0
Data Group	N/A	30	39000	39000	0	0
VoIP Group	N/A	30	13000	13000	0	0
Total	40	40	65000	65000	0	0
Data Group	N/A	40	52000	52000	0	0
VoIP Group	N/A	40	13000	13000	0	0
Total	50	50	91000	91000	0	0
Data Group	N/A	50	78000	78000	0	0
VoIP Group	N/A	50	13000	13000	0	0
Total	60	60	104000	104000	0	0
Data Group	N/A	60	91000	91000	0	0
VoIP Group	N/A	60	13000	13000	0	0
Total	70	70	117000	117000	0	0
Data Group	N/A	70	104000	104000	0	0
VoIP Group	N/A	70	13000	13000	0	0
Total	80	80	130000	130000	0	0
Data Group	N/A	80	117000	117000	0	0
VoIP Group	N/A	80	13000	13000	0	0
Total	90	90	156000	156000	0	0
Data Group	N/A	90	143000	143000	0	0
VoIP Group	N/A	90	13000	13000	0	0
Total	100	100	169000	169000	0	0
Data Group	N/A	100	156000	156000	0	0
VoIP Group	N/A	100	13000	13000	0	0

Table 36. MRV’S SMART BITS DATA AT RAYTHEON

The exciting portion of this day’s testing was when both technologies (FSO and RFM) were integrated. Only MRV’s Terescope 5000 made this combination possible. The product and its capabilities are explained in the next section of testing.

h. MRV-RFM Switchover

The RFM was connected to the MRV manufactured media converter. This converted the CAT 5 Ethernet from the RFM to fiber to feed the Terescope 5000 scope. The Terescope 5000 has two optical connections: one is for the direct fiber feed and the other is the standby to another fiber or RF backup system. With the MRV patent Fusion feature, the auto switching from the FSO to RFM took place within 2 milliseconds. Therefore, there was little to no impact in the traffic being transmitted. The

Terescope 5000 Fusion is a bit different than the Terescope 3000 unit in that the auto switch over from the FSO to the RFM was done internally in the Terescope 5000 scope. There was no external switch required for this action, which really simplified the installation. The figure below shows an illustration of the Terescope 5000 with the built-in OptiSwitch feature (Figure 42).

Figure 43. MRV'S TERESCOPE 5000 WITH BUILT-IN OPTISWITCH

During the switchover portion of the experiment, MRV's Terescope was covered so that the RFM could pick up the link between local area networks. Simulated computer and VoIP data was being sent across the network via SmartBits. The laser was covered while SmartsBits was running. This process forced the RFM to pick up the link via the OptiSwitch. The table below is an excerpt of the SmartBits data collected while this experiment was in progress (Table 37). The packet loss was recorded at 50 percent due to the change between the FSO link and RFM.

Name	Load (%)	Throughput	Sent	Received	Lost	Loss (%)
Total	10	10	24000	12000	12000	50
Data Group	N/A	10	16000	8000	8000	50
VoIP Group	N/A	10	8000	4000	4000	50
Total	20	20	40000	20000	20000	50
Data Group	N/A	20	32000	16000	16000	50
VoIP Group	N/A	20	8000	4000	4000	50
Total	30	30	56000	28000	28000	50
Data Group	N/A	30	48000	24000	24000	50
VoIP Group	N/A	30	8000	4000	4000	50
Total	40	40	72000	36000	36000	50
Data Group	N/A	40	64000	32000	32000	50
VoIP Group	N/A	40	8000	4000	4000	50
Total	50	50	88000	44000	44000	50
Data Group	N/A	50	80000	40000	40000	50
VoIP Group	N/A	50	8000	4000	4000	50
Total	60	60	104000	52000	52000	50
Data Group	N/A	60	96000	48000	48000	50
VoIP Group	N/A	60	8000	4000	4000	50
Total	70	70	120000	60000	60000	50
Data Group	N/A	70	112000	56000	56000	50
VoIP Group	N/A	70	8000	4000	4000	50
Total	80	80	136000	68000	68000	50
Data Group	N/A	80	128000	64000	64000	50
VoIP Group	N/A	80	8000	4000	4000	50
Total	90	90	152000	76000	76000	50
Data Group	N/A	90	144000	72000	72000	50
VoIP Group	N/A	90	8000	4000	4000	50
Total	100	100	168000	84000	84000	50
Data Group	N/A	100	160000	80000	80000	50
VoIP Group	N/A	100	8000	4000	4000	50

Table 37. MRV'S OPTISWITCH SMART BITS DATA AT RAYTHEON

During the Smart Bits test, SolarWinds recorded a 54 Mbps throughput when the data was going across the FSO link and a 33 Mbps throughput when the data was going across the RFM link. Throughout the SmartBits testing, SolarWinds did not drop the link (the term "not drop the link" indicated that the link remained operational while the switchover occurred between media links).

The last day of testing was very exciting; a new technology was introduced to the authors of this thesis. The new technology was Orthogonal Frequency Division Multiplexing (OFDM). Alvarion demonstrated their OFDM product, which has BLOS capability. Alvarion's OFDM product is explained in the BLOS section of the Raytheon testing. Also on the last day of testing, the Iridium Inverse Multiplexer

(IMUX) was tested. The IMUX test can be found in the OTH section of the Raytheon testing. Another FSO company, fSONA, was tested at the 6.7 kilometer range.

i. fSONA

The company, fSONA, brought the same product, SONAbeam 155-M, as the previous testing evolutions. The personnel that fSONA sent to support the experiments were Mike Corcoran, Senior Vice President of Sales and Marketing; Kelly Irvin, Director Western Sales; Pablo Bandera, fSONA's Product Manager; and Sean Dante, Field Technician. The equipment took roughly 45 minutes to set up and align. The series of testing included an Iperf data test, a data file transfer test monitored by SolarWinds, and a Smart Bits test.

The Iperf test consisted of nine data runs. Six of the data runs were conducted with fSONA's equipment uncovered (without any crypto, KG-235). The window size was manipulated in order to obtain the maximum throughput for the link being tested. Then, three data runs were conducted using the KG-235s for bulk encryption (results were discussed earlier in this thesis). The maximum throughput obtained without using the KG-235 is represented below.

```
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  0.1 MByte
------------------------------------------------------------
[920] local 192.168.3.3 port 5001 connected with 192.168.1.2 port 1038
[ ID] Interval        Transfer       Bandwidth
[920]  0.0- 1.0 sec   10.9 MBytes    87.1 Mbits/sec
[920]  1.0- 2.0 sec   11.0 MBytes    88.1 Mbits/sec
[920]  2.0- 3.0 sec   11.3 MBytes    90.2 Mbits/sec
[920]  3.0- 4.0 sec   11.3 Mbytes    90.1 Mbits/sec
[920]  4.0- 5.0 sec   10.8 Mbytes    86.1 Mbits/sec
[920]  5.0- 6.0 sec   11.3 Mbytes    90.1 Mbits/sec
[920]  6.0- 7.0 sec   11.1 Mbytes    89.2 Mbits/sec
[920]  7.0- 8.0 sec   11.3 Mbytes    90.1 Mbits/sec
[920]  8.0- 9.0 sec   11.3 Mbytes    90.1 Mbits/sec
[920]  9.0-10.0 sec   11.3 MBytes    90.1 Mbits/sec
[920]  0.0-10.0 sec    112 MBytes    89.2 Mbits/sec
```

The data transfer test monitored by SolarWinds consisted of 16 runs of data transfer. The first series of data transfer was conducted while VoIP was being used across the link. The second series of data transfer was conducted while VoIP was being used and a video camera also streamed video across the link. Additionally, each

CAC2S to CAC2S fSONA 6.7km							
Run No.	**Media**	**Size**	**Time**	**Throughput**	**Loss (%)**	**VOICE**	**VIDEO**
VOICE AND DATA							
1	FSO	1.5 M	1"	3.43M	0	YES	NO
2	FSO	5 M	1"	7.96M	0	YES	NO
3	FSO	10 M	2"	15M	0	YES	NO
4	FSO	75 M	15"	53M	0	YES	NO
5	FSO	150 M	30"	50M	0	YES	NO
6	FSO	300 M	1'00"	45M	0	YES	NO
7	FSO	600 M	2'10"	50M	0	YES	NO
8	FSO	1.2 GIG	4'26"	45M	0	YES	NO
VOICE, DATA, AND VIDEO							
9	FSO	1.5 M	1"	2.91M	0	YES	YES
10	FSO	5 M	1"	8M	0	YES	YES
11	FSO	10 M	2"	16M	0	YES	YES
12	FSO	75 M	12"	45M	0	YES	YES
13	FSO	150 M	30"	52M	0	YES	YES
14	FSO	300 M	52"	52M	0	YES	YES
15	FSO	600 M	2'20"	50M	0	YES	YES
16	FSO	1.2 GIG	5'15"	36M	0	YES	YES

computer was running video on the computer as the test was being conducted. The table below indicates the data obtained while this test was conducted (Table 38).

Table 38. fSONA SOLARWINDS DATA AT RAYTHEON

The next series of tests were conducted using SmartBits. During this series of testing, SmartBits simulated 100 computers passing data across the two networks and 24 simulated phone conversations passing information across the network. Out of all the technologies tested, fSONA had the lowest frame loss percentage. The frame loss percentage was .00118 %. This low frame loss percentage may be a result of fSONA’s lasers being able to produce a power output of 640 milliwatts, a considerable difference over all other companies. The network was stressed by applying data in 10 Mbyte increments until the network was passing 100 Mbytes of data. The table below is an excerpt of the data obtained by SolarWinds (Table 39).

Name	Load (%)	Throughput	Sent	Received	Lost	Loss (%)
Total	10	10	26000	26000	0	0
Data Group	N/A	10	13000	13000	0	0
VoIP Group	N/A	10	13000	13000	0	0
Total	20	20	39000	39000	0	0
Data Group	N/A	20	26000	26000	0	0
VoIP Group	N/A	20	13000	13000	0	0
Total	30	30	52000	52000	0	0
Data Group	N/A	30	39000	39000	0	0
VoIP Group	N/A	30	13000	13000	0	0
Total	40	40	65000	65000	0	0
Data Group	N/A	40	52000	52000	0	0
VoIP Group	N/A	40	13000	13000	0	0
Total	50	50	91000	91000	0	0
Data Group	N/A	50	78000	78000	0	0
VoIP Group	N/A	50	13000	13000	0	0
Total	60	60	104000	104000	0	0
Data Group	N/A	60	91000	91000	0	0
VoIP Group	N/A	60	13000	13000	0	0
Total	70	70	117000	117000	0	0
Data Group	N/A	70	104000	104000	0	0
VoIP Group	N/A	70	13000	13000	0	0
Total	80	80	130000	130000	0	0
Data Group	N/A	80	117000	117000	0	0
VoIP Group	N/A	80	13000	13000	0	0
Total	90	90	156000	156000	0	0
Data Group	N/A	90	143000	143000	0	0
VoIP Group	N/A	90	13000	13000	0	0
Total	100	100	169000	168998	2	0.00118
Data Group	N/A	100	156000	155998	2	0.00128
VoIP Group	N/A	100	13000	13000	0	0

Table 39. fSONA'S SMARTBITS DATA AT RAYTHEON

The technologies used in the line-of-sight testing showed potential to be implemented in both a UOC and CAC2S architecture. A key tool used in determining the quality of the link across the network is the VoIP. The next section will briefly discuss VoIP.

j. Voice Over Internet Protocol (VoIP)

LT Manny Cordero has been studying VoIP at NPS. LT Cordero's thesis involves VoIP and his contributions in providing a mixture of equipment and expertise was key to this thesis research.

The IP telephones used were the Cisco 7960G. The telephones were connected to the network via CAT-5 cable to the Cisco switch. Present at the MRF was the Call Manager server that managed the IP phones in the network. The server assigned each phone its own IP address, which enabled any phone within the network to place a call to any other phone in the network.

In the following sections VoIP was utilized with a BLOS company called Alvarion. While conducting the data transfer test, SolarWinds would indicate the link being down. However, the VoIP phone call was still operating across the link. The next section will discuss a Beyond line of Sight (BLOS) technology by Alvarion.

1. Beyond Line-of-Sight (BLOS)

Alvarion from Carlsbad, California, introduced a product that operated in a non-line-of-sight (NLOS) mode. Since the product operates in a NLOS mode, the BLOS problem was tested at a distance of 6,700 meters in order to demonstrate the capability.

a. Alvarion

The Alvarion personnel who supported this evolution were Director of Strategic Marketing, Jasper Bruinzeel, and field technicians Willie Alayza and Soria Constantino. The product introduced to the testing was Alvarion's BreezeACCESS VL system. The system is a point-to-multi-point or point-to-point system. The system operates in the 5 GHz frequency band (5.725-5.850 GHz). The BreezeACCESS uses OFDM technology in order to overcome the BLOS problem. The product can operate in speeds of 6 Mbps, 24 Mbps, and 54 Mbps. The product used had an antenna and radio built into one unit. There are different versions of this product, so the antennas come in different sector types. The antennas can be directional or omni-directional. The type of equipment is determined by the application requirement the equipment needs to address.

The testing data obtained resulted from an Iperf test and a SmartBits test. The Iperf test was conducted with and without the KG-235. Several runs were conducted in order to maximize the throughput across the link. In addition to adjusting the window size, the antenna was changed. The Iperf test started with a SU-VL integrated antenna with a 10-degree beam width and a 21 dB gain on the BreezeACCESS. While the Iperf test was being conducted, a VoIP call was made along with streaming video. There were three runs conducted with the SU-VL antenna. The maximum throughput results from the small antenna are indicated below.

```
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  0.1 MByte
------------------------------------------------------------
[920] local 192.168.3.3 port 5001 connected with 192.168.1.2 port 1045
[ ID] Interval        Transfer      Bandwidth
[920]  0.0- 1.3 sec   0.2 MBytes    1.3 Mbits/sec
[920]  1.3- 2.2 sec   0.2 MBytes    1.6 Mbits/sec
[920]  2.2- 3.5 sec   0.3 MBytes    1.6 Mbits/sec
[920]  3.5- 4.1 sec   0.3 MBytes    4.2 Mbits/sec
[920]  4.1- 5.1 sec   0.2 MBytes    1.7 Mbits/sec
[920]  5.1- 6.1 sec   0.3 MBytes    2.7 Mbits/sec
[920]  6.1- 7.1 sec   0.5 MBytes    3.9 Mbits/sec
[920]  7.1- 8.0 sec   0.4 MBytes    4.1 Mbits/sec
[920]  8.0- 9.0 sec   0.9 MBytes    6.9 Mbits/sec
[920]  9.0-10.0 sec   0.4 MBytes    3.0 Mbits/sec
[920]  0.0-10.3 sec   3.8 MBytes    2.9 Mbits/sec
```

A larger antenna, a two-foot Uni-directional antenna with a 28.5 dB gain and 3 dB beamwidth of 4.5 degrees, was attached to the BreezeACCESS. Two runs were conducted with the Uni-directional antenna while the streaming video camera and VoIP were operational in the background. The data below represents the maximum throughput data obtained from these runs.

```
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  0.1 MByte
------------------------------------------------------------
[920] local 192.168.3.3 port 5001 connected with 192.168.1.2 port 1050
[ ID] Interval        Transfer      Bandwidth
[920]  0.0- 1.9 sec   0.0 MBytes    0.1 Mbits/sec
[920]  1.9- 2.0 sec   0.2 MBytes    9.0 Mbits/sec
[920]  2.0- 3.1 sec   0.7 MBytes    5.2 Mbits/sec
[920]  3.1- 4.1 sec   0.7 MBytes    5.4 Mbits/sec
[920]  4.1- 5.0 sec   0.4 MBytes    3.3 Mbits/sec
[920]  5.0- 6.5 sec   0.5 MBytes    2.4 Mbits/sec
[920]  6.5- 7.0 sec   0.5 MBytes    9.1 Mbits/sec
[920]  7.0- 8.0 sec   0.5 MBytes    3.6 Mbits/sec
[920]  8.0- 9.3 sec   0.5 MBytes    2.8 Mbits/sec
[920]  9.3-10.2 sec   0.3 MBytes    2.5 Mbits/sec
[920]  0.0-10.2 sec   4.1 MBytes    3.2 Mbits/sec
```

The KG-235 was placed between the BreezeACCESS equipment and the Cisco router. There were several runs conducted with the window size changed on each run. While the Iperf data tests were running, VoIP and streaming video was running in the background. The following Iperf data represents the maximum throughput data obtained with the KG-235s in the network.

```
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  0.1 MByte
------------------------------------------------------------
[920] local 192.168.1.25 port 5001 connected with 192.168.3.25 port 1811
[ ID] Interval          Transfer       Bandwidth
[920]  0.0- 1.0 sec     0.3 MBytes     2.7 Mbits/sec
[920]  1.0- 2.1 sec     0.2 MBytes     1.8 Mbits/sec
[920]  2.1- 3.3 sec     0.4 MBytes     2.3 Mbits/sec
[920]  3.3- 4.0 sec     0.3 MBytes     3.1 Mbits/sec
[920]  4.0- 5.2 sec     0.2 MBytes     1.6 Mbits/sec
[920]  5.2- 6.1 sec     0.2 MBytes     1.9 Mbits/sec
[920]  6.1- 7.0 sec     0.3 MBytes     2.5 Mbits/sec
[920]  7.0- 8.0 sec     0.4 MBytes     2.9 Mbits/sec
[920]  8.0- 9.0 sec     0.3 MBytes     2.6 Mbits/sec
[920]  9.0-10.0 sec     0.3 MBytes     2.7 Mbits/sec
[920]  0.0-10.1 sec     3.0 MBytes     2.4 Mbits/sec
```

The final test conducted with Alvarion was the SmartBits test. During the SmartBits test, 100 computers were simulated passing data across the network with data increments of 10 Mbytes until a maximum throughput of 30 Mbytes was reached. The table below represents an excerpt of the data obtained while conducting the SmartBits test (Table 40).

Name	Load (%)	Throughput	Sent	Received	Lost	Loss (%)
Total	5	5	8126	8126	0	0
Data Group	N/A	5	8126	8126	0	0
Total	10	10	16254	16253	1	0.00615
Data Group	N/A	10	16254	16253	1	0.00615
Total	15	15	24382	18840	5542	22.7299
Data Group	N/A	15	24382	18840	5542	22.7299
Total	20	20	32508	20813	11695	35.9758
Data Group	N/A	20	32508	20813	11695	35.9758
Total	25	25	40636	20709	19927	49.0378
Data Group	N/A	25	40636	20709	19927	49.0378
Total	30	30	48764	20600	28164	57.7557
Data Group	N/A	30	48764	20600	28164	57.7557

Table 40. ALVARION'S SMARTBITS DATA AT RAYTHEON

Figure 43 indicates a frame size of 1,518 Kbytes and a throughput of 30 Mbps on the left and a frame loss of 57.8% on the right. The reason for the large frame loss is that the throughput oversaturated the link and packets were lost during this state of exchange between the sites.

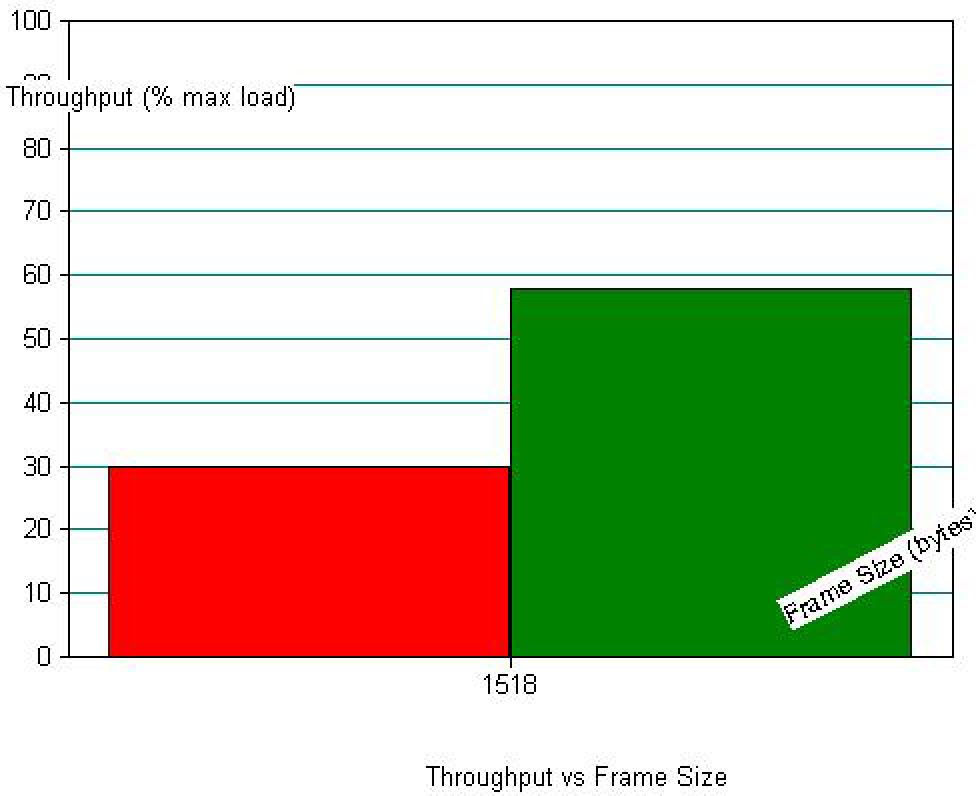

Figure 44. ALVARION'S SMARTBITS GRAPH AT RAYTHEON

The final experiment conducted at Raytheon was the Iridium Inverse Multiplexer. This technology provided OTH connectivity and is explained in the following section.

2. Over-the-Horizon (OTH)

a. IMUX

The IMUX, as described in earlier testing, is a product that gives the warfighter OTH capability on the battlefield. As described in the General Dynamics testing earlier in this thesis, Dr. Glenn Abousleman utilized his compression algorithm over the limited throughput Iridium satellite architecture. The data obtained from the IMUX was the Iperf test data. Carey Foushee, General Dynamics Decision Systems field engineer, was the engineer who made the IMUX operational. Several data runs were conducted with the IMUX. The excerpt below is an example of the Iperf data collected from the test.

```
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size: 62.7 KByte
------------------------------------------------------------
[920] local 192.168.3.3 port 5001 connected with 192.168.1.2 port 1050
[ ID] Interval       Transfer     Bandwidth
[920]  0.0- 3.0 sec   1.9 KBytes    5.2 Kbits/sec
[920]  3.0- 5.5 sec   1.9 KBytes    6.1 Kbits/sec
[920]  5.5- 7.8 sec   3.4 KBytes   11.7 Kbits/sec
[920]  7.8- 9.0 sec   1.0 KBytes    6.5 Kbits/sec
[920]  9.0-10.1 sec   4.3 KBytes   31.1 Kbits/sec
[920] 10.1-11.5 sec   4.3 KBytes   24.1 Kbits/sec
[920] 11.5-12.1 sec   0.5 KBytes    6.9 Kbits/sec
[920] 12.1-14.3 sec   3.4 KBytes   12.5 Kbits/sec
[920] 14.3-16.7 sec   1.9 KBytes    6.2 Kbits/sec
[920] 16.7-18.8 sec   1.2 KBytes    4.6 Kbits/sec
[920] 18.8-20.5 sec   0.5 KBytes    2.3 Kbits/sec
[920] 20.5-21.3 sec   0.7 KBytes    7.2 Kbits/sec
[920] 21.3-25.7 sec   1.7 KBytes    3.1 Kbits/sec
[920] 25.7-27.9 sec   1.2 KBytes    4.4 Kbits/sec
[920] 27.9-30.2 sec   1.2 KBytes    4.2 Kbits/sec
[920] 30.2-32.6 sec   1.2 KBytes    4.0 Kbits/sec
[920] 32.6-36.9 sec   1.7 KBytes    3.1 Kbits/sec
[920] 36.9-38.7 sec   0.5 KBytes    2.2 Kbits/sec
[920] 38.7-39.1 sec   0.7 KBytes   12.8 Kbits/sec
[920] 39.1-41.4 sec   1.2 KBytes    4.2 Kbits/sec
```

The testing interval was extended up to 112 seconds for each of these runs. The average throughput observed was 9.6 Kbps during the runs. The compression algorithm observed in the Mobile Research Facility showed that a several Mbyte picture was compressed and sent over the Iridium link within seconds. This would have taken close to an hour without the compression algorithm applied.

The following section will discuss the KG-235 In-Line Network Encryptor (INE). The INE was used with the IMUX and the results were on average 9.6 Kbps of throughput across the link. Additionally, the KG-235 bulk encryption was tested throughout the experiment with different technologies.

b. Crypto (INE)

GDDS provided two KG-235 Sectéra INE and field engineer, Carey Foushee made them operational. The manufacturer of this product is GDDS. The purpose of utilizing these devices was to secure the link between the two local area networks and to observe any noticeable difference in the throughput while applying encryption. When using the INE with the IMUX, 9.6 Kbps was observed as an average throughput. Throughout the week, Mr. Foushee diligently established the link between the two networks. The line of sight companies tested with the INE were Terabeam and fSONA. Their results were discussed earlier in this thesis. The results from the BLOS company tested, Alvarion, can be found in the Alvarion section of this thesis.

The testing at Raytheon proved to be interesting and educational. In March, a combination of all these technologies was integrated at Camp Roberts, California.

D. FIELD TEST #4 (CAMP ROBERTS)

From March 7-11, 2004 at Camp Roberts, CA, seven NPS students, four Marines from Marine Air Support Squadron 6 out of Miramar Air Station, and several vendors participated in communications testing which emulated a Marine Corps tactical environment. The student participants from NPS were Captain Gilbert Garcia, Captain David Joseforsky, LT Manny Cordero, LT Albert Seeman, LT Ryan Blazevich (USN), Captain Ray Munoz (USMC), and Captain Rob Guice (USMC).

Line-of-sight (LOS), beyond-line-of-sight (BLOS), and over-the-horizon (OTH) communications were set up and tested while at Camp Roberts for the following scenarios: Command and Control On-the-Move Network Digital Over-the-Horizon Relay (CoNDOR), communications on-the-move, and airborne relay. First, the CoNDOR scenario was set up with two remote sites located within LOS of a Point of Presence (POP) site. This occurred with FSO equipment provided by Lightpointe and Terabeam. In addition, the two sites were moved BLOS from the POP in order to use an Orthogonal Frequency Division Multiplexing (OFDM) product provided by Alvarion and Redline Communications. The remote sites to the POP simulated a company-battalion relationship. The POP site was furnished with a high throughput satellite link that communicated back to the Network Operations Center (NOC), which resembled a battalion-regiment relationship. Segovia provided the satellite service and the satellite dishes were furnished by Omega Systems.

Second, two vehicles, Mobile Radio Component (MRC) #1 and MRC #2, simulated a convoy driving through the training area which formulated the communications on-the-move setup. This was done with the vehicles BLOS of each other, so they communicated via OFDM equipment from Alvarion and Redline Communications. One vehicle in the convoy, MRC #1, also had an INMARSAT satellite link on the final day of the exercise, which was operated separate from the established network. An 802.11b link was established between the lead convoy vehicle and the POP site via a tethered balloon. This enabled all vehicles in that convoy to communicate with the POP site. In addition, each vehicle in the convoy had its own wireless LAN via an 802.11a Access Point.

Lastly, the authors employed a tethered balloon and Unmanned Aerial Vehicle (UAV) over the training area as a means to extend the network. They did this by employing 802.11b omni-directional antennas at each site: MRC #1, POP, NOC, and on the airborne platforms. The tethered balloon retransmitted 802.11b signals between the lead vehicle in the convoy and the POP site. MLB Company's UAV platform was employed as an airborne relay as well, but it was not employed within the network.

The original intent was to use the Cisco Mobile Access Router (MAR), a hand sized router made up of a stack of different cards, at each of the ground nodes as a device that could accept multiple technologies at the same time from multiple sites. For example, if at the POP three different types of technologies were coming in and a LAN was required, then four Ethernet ports that were layer 3 capable would be needed. Since the regular Cisco routers available for this testing event only had two layer 3 Ethernet ports available on each device, one router could not accomplish the task. In addition, the students intended to test the MARs in the airborne platforms by connecting two different types of technologies to the MAR at the same time. If the MAR sensed that the primary means of transmission degraded, then it would automatically switch to the secondary means. Figure 44 below shows the MAR.

Figure 45. MOBILE ACCESS ROUTER[48]

Unfortunately, after days of working on the MAR's configurations, the students and the commercial company on-hand to assist, Western DataCom, could not get these devices to function properly. Since the MARs were not operational, the students decided to use the Cisco 3745 and 2600 series routers in a variety of ways: connecting two routers together, inserting a switch between the routers, and utilizing the Cisco 3550 Switch as a layer 3 device to route.

In order to bring all the above scenarios together by the end of the week, the students conducted the testing in a step-by-step fashion where each scenario was tested individually. On 8 March, three nodes were used: NOC, POP, and MRC #1. The NOC and POP were separated by about 2 kilometers and a hill. Thus, the two sites maintained communication via an OFDM link in non-line-of-sight mode. At the POP, a Cisco 2950 Switch was placed between the two Cisco routers in order to facilitate OFDM and FSO links, as well as a LAN. This was done because each router had only two Ethernet ports that were layer 3 capable, and the switch was a layer 2 device. Next, the students established a LOS situation between the POP and MRC #1 at about 1,000 meters. The connectivity between the two sites was established with an FSO link. Finally, in order to facilitate coordination between all sites, single-channel voice communications were attained via VHF and HF manpack radios. The VHF net was on a PRC-119 radio that was remoted into the LAN area with an A/N GRA-39. The NOC was equipped with an OE-254 long range VHF antenna, while the other two sites used 10-foot whip antennas. In addition to the VHF net, an A/N PRC-104 provided redundant communications on an HF net. Figure 45 below illustrates the setup.

48 http://www.cisco.com/en/US/products/hw/routers/ps272 (May 2004).

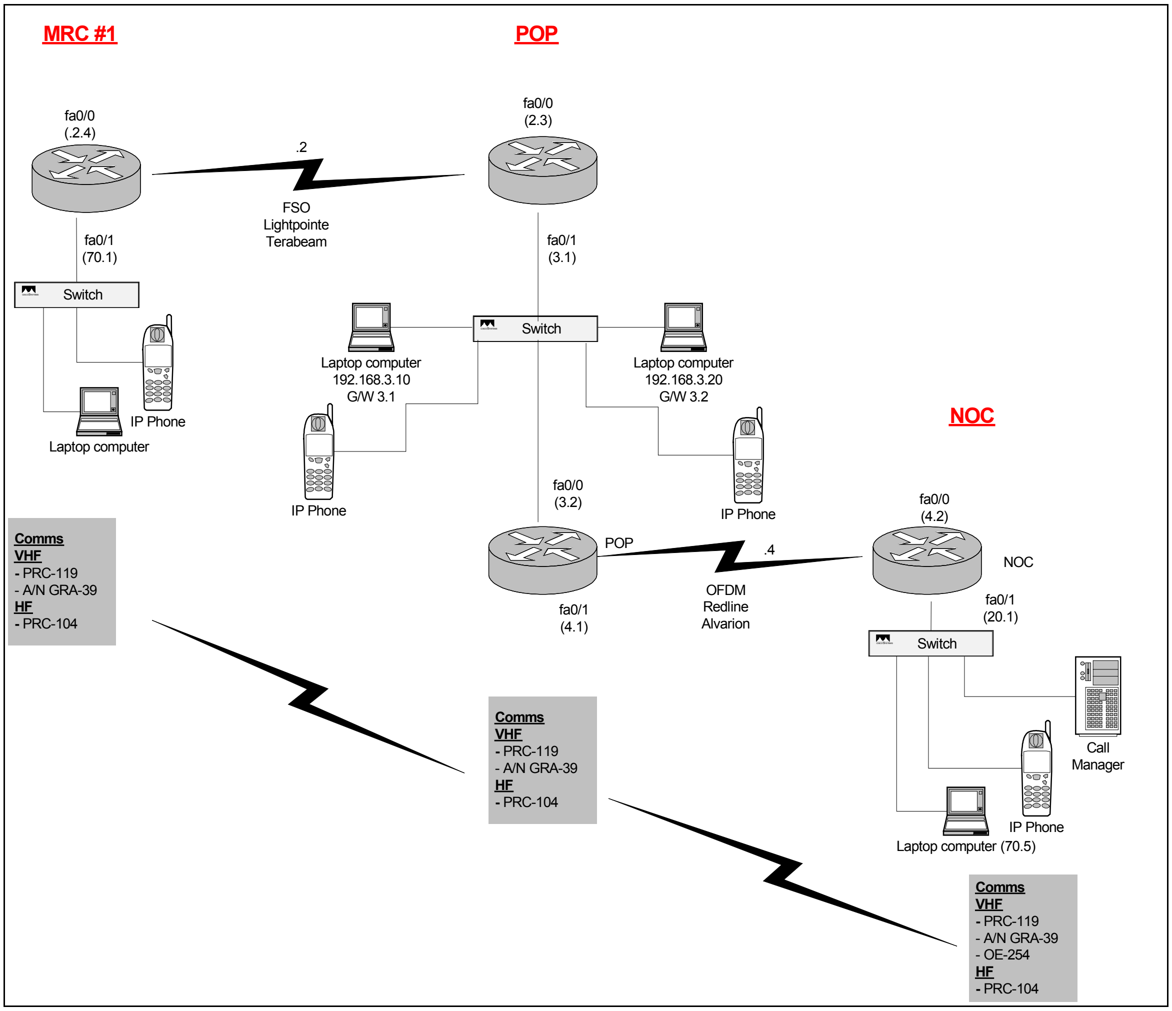

Figure 46. 8 MARCH COMMUNICATIONS ARCHITECTURE

On 9 March, several additions and changes were made to the communications architecture. First, MRC site #2 was added in order to facilitate two nodes communicating with the POP site. MRC #1 was LOS with the POP using an FSO link at about 1,000 meters, and MRC #2 was BLOS with the POP using OFDM technology also at about 1,000 meters. The POP was now connected with the NOC via a broadband satellite link.

At the POP site, a Cisco 3550 Switch replaced the router-switch combination. This facilitated one device being able to handle three different technologies at the same time, such as FSO, OFDM, and broadband satellite, and also a LAN. The 3550 Switch is a Layer 2/3 capable device, which means that it is capable of routing traffic. Unfortunately, the students were unable to program a routing protocol into the switch. Thus, the switch could not automatically establish a routing table to talk with the other wide area network routers, which were using Enhanced Interior Gateway Routing Protocol (EIGRP). Ross Warren from Segovia and LT Cordero had to manually input all the routes into the routers and Cisco 3550 Switch so the devices would know where to find each other.

Finally, single-channel voice communications were again established with the PRC-119s and PRC-104s. These were vital assets as coordination took place to get each of the links established and to conduct the days test. The tethered balloon was also employed on this day as a means of communication between the NOC and the POP sites. The tethered balloon and the satellite link were not redundant communications, but they were employed separately on the network. In order to do this, the students unplugged the satellite link from the network and plugged the 802.11b link into the same ports that the satellite was hooked into. Figure 46 below gives further detail of this day's setup.

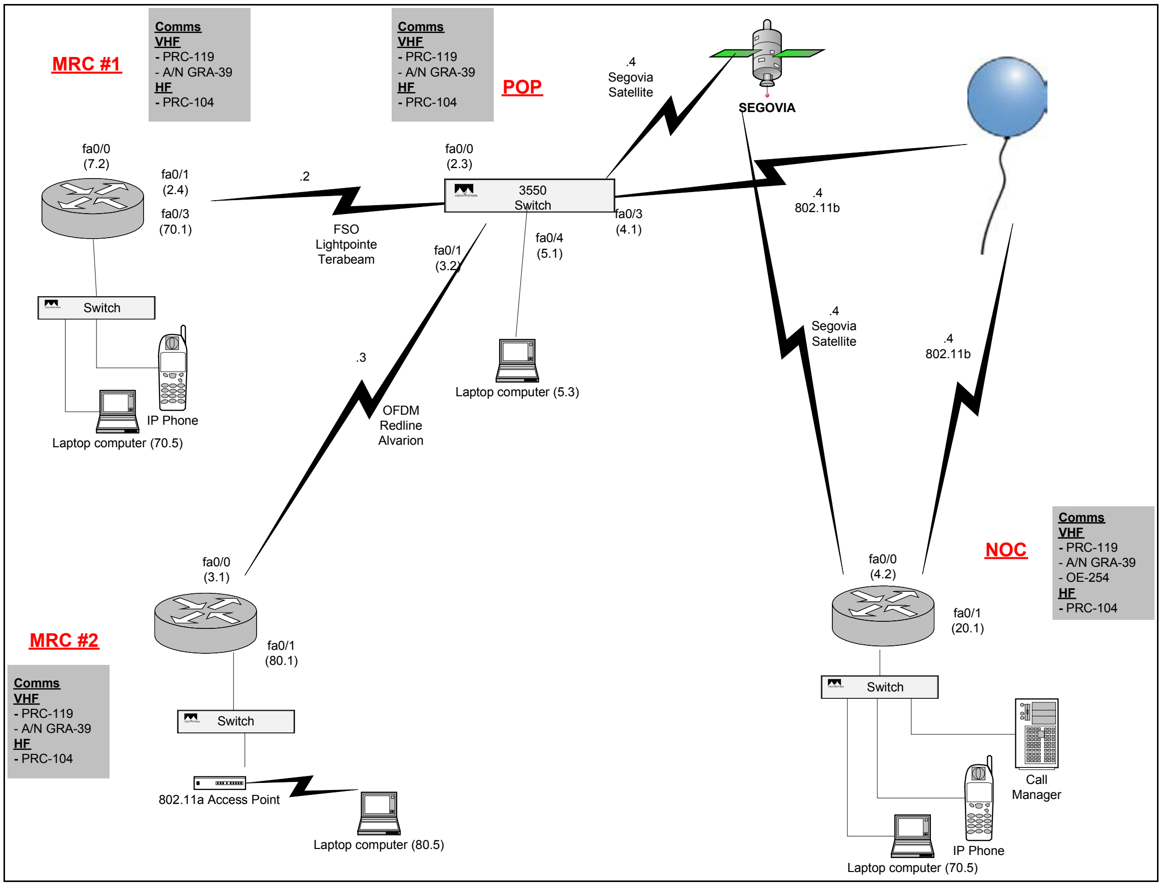

Figure 47. 9 MARCH COMMUNICATIONS ARCHITECTURE

The next day of testing, 10 March, was the first attempt to incorporate all scenarios mentioned above. Communications on-the-move was performed by MRC #1 and #2, as both vehicles had their own LAN setup in the vehicles. The objective of the experiments with these vehicles was to simulate a convoy where the vehicles did not have LOS communications. Thus, the two vehicles drove BLOS of each other and OFDM technology was utilized to keep the vehicles in contact with each other. Next, FSO was employed in MRC #1 and #2 when the vehicles planned to stop and attain LOS with one another. The OFDM link and FSO were not used simultaneously, but were rather used separate from each other.

The lead vehicle, MRC #1, was also equipped with an omni-directional antenna to establish communication with the POP through the tethered balloon with 802.11b. The same setup was employed at the POP and NOC as the previous day with the Cisco 3550

Switch at the POP and the broadband satellite equipment connecting the two sites. The addition on this day was integration of an UAV into the setup. This platform was employed off of the network at various times throughout the day in order to test the reliability of its communications relay. The UAV and tethered balloon were used as aerial relay platforms of 802.11b.

Finally, VHF voice communications were used throughout the day. This greatly assisted all the nodes to communicate while the vehicles were in motion. Figure 47 below portrays the architecture on this day.

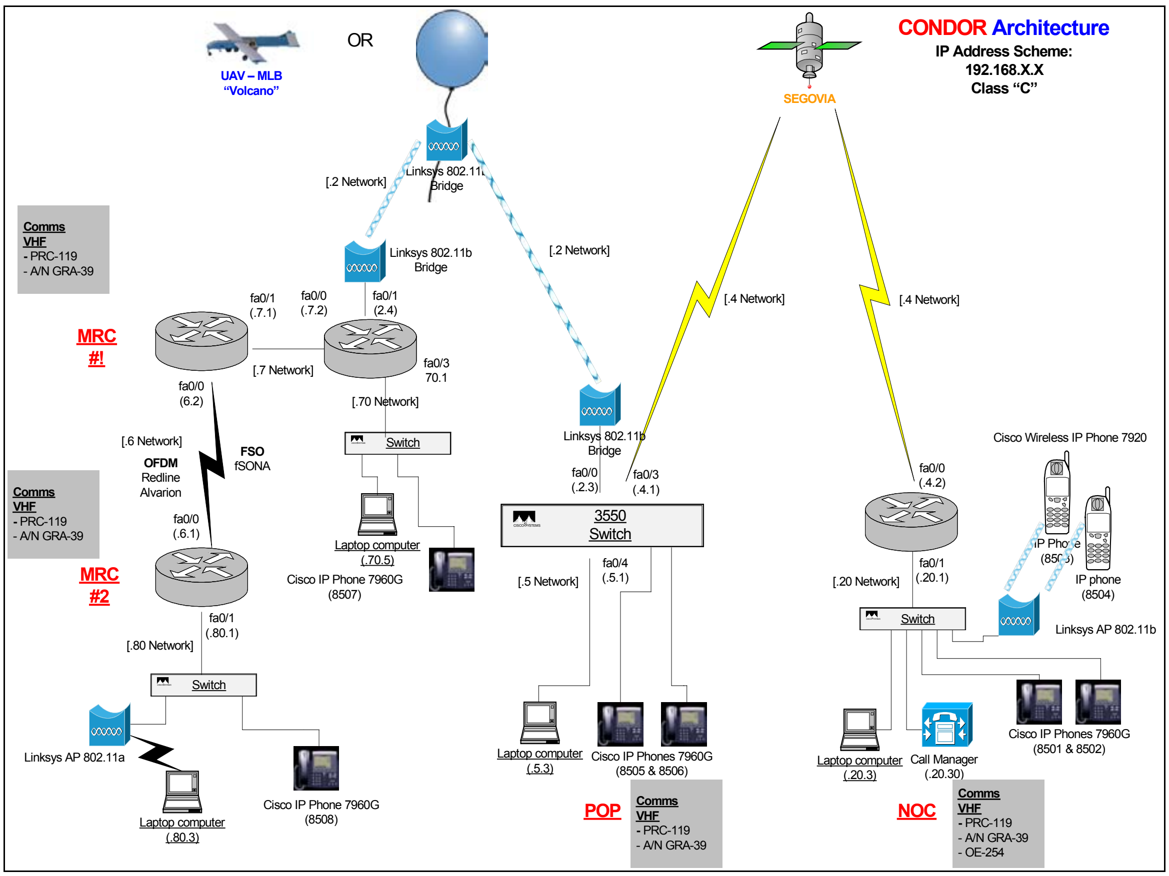

Figure 48. 10 MARCH COMMUNICATIONS ARCHITECTURE

On 11 March, except for one change at MRC #1 and the addition of the INMARSAT, the communications architecture was the same as the previous day. MRC #1 and #2 were still conducting communications on-the-move, along with static connectivity using FSO. At MRC #1, based on the previous day's lessons learned, the students decided to place the Cisco 2950 switch between the two routers in order to facilitate the connections of 802.11b, OFDM/FSO, and a LAN. During the previous day, an attempt was made to install a module on the Cisco 3745 router that had multiple IP ports. Unfortunately, the ports on the module were unable to perform layer 3 capabilities, so the students had to employ a method that was used at the POP on the first day of testing. This assisted in getting the LAN established at MRC #1.

The INMARSAT link was utilized at MRC #1, but communications were never established with the network. Instead of using it as originally intended in place of the tethered balloon, the students used the INMARSAT service to search the Internet and make test phone calls while on the move in MRC #1. A phone was placed at MRC #1 and at the NOC to test the phone connectivity.

Once again single-channel voice communications were utilized between all the nodes to facilitate planning and coordination. Figure 48 below displays the architecture on this day.

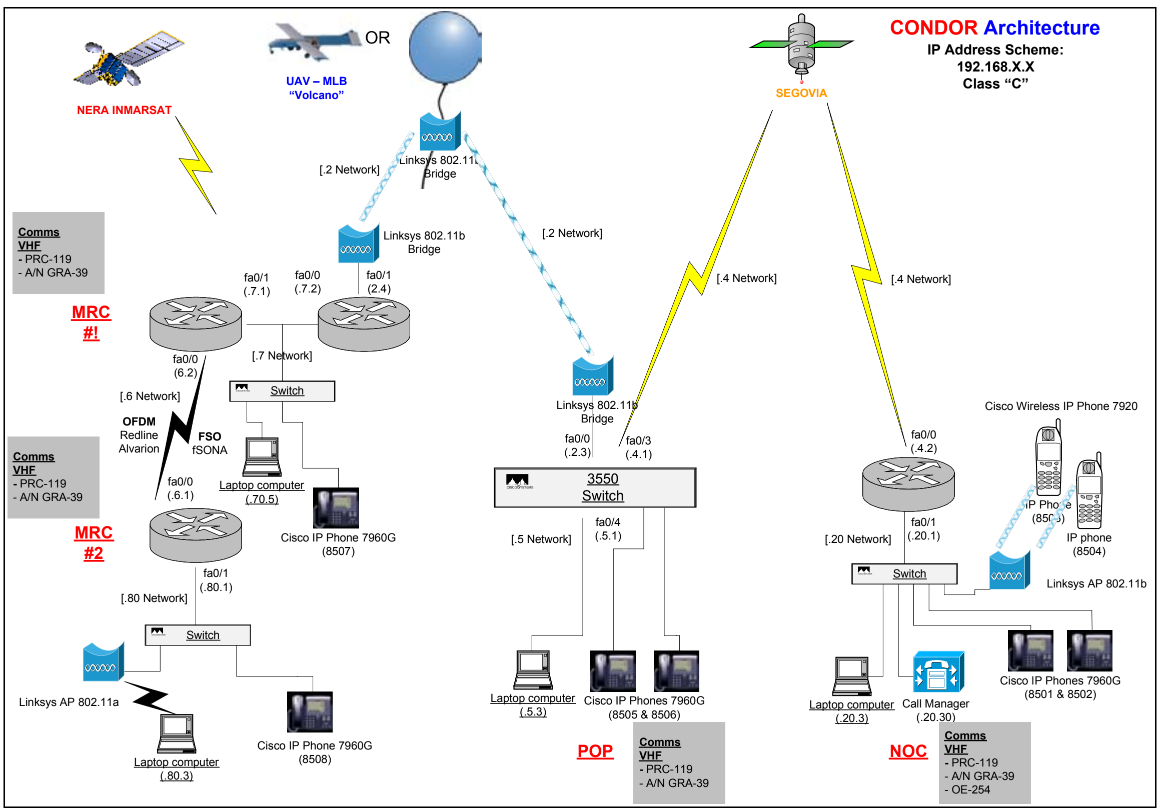

Figure 49. 11 MARCH COMMUNICATIONS ARCHITECTURE

The ultimate goal of this testing event was to determine which of the technologies evaluated proved useful while employed during the above scenarios. In addition, the authors evaluated how the technologies reacted to one another when merged together throughout the WAN's communications architecture. The focus was not on data collection of throughput rates as in previous field tests. The following state-of-the-art wireless technologies were tested: Free Space Optics, 802.11b, 802.11a, OFDM, INMARSAT, and Broadband Satellite. Voice over Internet Protocol (VoIP) was implemented in the local area networks to test the quality of service over this multitude of technologies.

1. Line-of-Sight (LOS)

a. Lightpointe

Lightpointe supported the testing evolution from March 7-9 with Jim McGowan, Sales Director, and Albert Borquez, Network Engineer. They brought their FlightStrata OC-3 FSO Fly Away Package, which included two link heads for end-to-end connectivity. Lightpointe's personnel arrived on 7 March in order to assist in the baseline testing being conducted. They set up a short 50-meter link on this day. Due to the FlightStrata's Auto Power Control, the short distance was easily accomplished. They were configured similarly to the Raytheon testing event where they ran a multi-mode fiber cable from the link head to a media converter and then from the converter to the network router via CAT-5 cable. The main focus of this day's experiments was to ensure the network equipment was working appropriately before gear and personnel moved to the training area the next day.

On 8 March, Lightpointe established one link at MRC #1 and the other at the POP site. The purpose of this day's experiments was to establish connectivity from the NOC to the POP via OFDM and from the POP to MRC #1 through FSO. The distance between MRC #1 to the POP was about 1,000 meters. Terabeam was setup at MRC #1 as well on this day. The authors managed to switch the links of both companies in and out of the network, so they did not operate simultaneously. Figure 49 shows the setup of the links at MRC #1.

Figure 50. LIGHTPOINTE AND TERABEAM SETUP AT MRC #1 ON 8 MARCH

When going from the NOC to the POP via OFDM then to the MRC #1 site via Lightpointe's FSO link, two tests were conducted using Iperf on 8 March. A sample set of data from this experiment can be found in Figure 50 below.

```
------------------------------------------------------------
Client connecting to 192.168.70.5, TCP port 5001
TCP window size: 63.0 KByte (default)
------------------------------------------------------------
[928] local 192.168.20.3 port 1420 connected with 192.168.70.5 port 5001
[ ID] Interval        Transfer      Bandwidth
[928]  0.0- 5.2 sec   2.7 MBytes    4.1 Mbits/sec
[928]  5.2-10.1 sec   1.8 MBytes    2.9 Mbits/sec
[928] 10.1-15.0 sec   3.9 MBytes    6.3 Mbits/sec
[928] 15.0-20.0 sec   3.4 MBytes    5.4 Mbits/sec
[928]  0.0-20.3 sec   11.7 MBytes   4.6 Mbits/sec
```

Figure 51. IPERF DATA FROM NOC TO MRC #1 ON 8 MARCH

While these data rates are very low for an FSO link, the bandwidth was actually dictated by the OFDM link that was being used from the NOC to the POP, which was BLOS. See the Findings and Analysis section for further explanation.

On 9 March, Lightpointe set up their link at MRC site #1 once again with Terabeam. MRC site #2 was set up with an OFDM link between the site and the POP, and the POP was connected to the NOC via Segovia/Omega Systems satellite link. That way, the NOC was communicating through the satellite to the POP and from there to MRC #1 via FSO. Although the links were successfully established, the authors were unable to ping between the NOC and MRC #1 on this day due to routing issues on the Cisco 3550 switch at the POP.

Overall, Lightpointe was able to display the diversity of their Fly Away package while maneuvering around the training area. Their personnel and product support was top notch during this testing evolution.

b. Terabeam

Terabeam supported this evolution with Craig Campadore, Sales, and Wayne Bailey, Engineer, from March 7-9. They brought Terabeam's outdoor Elliptica OC-3 FSO product with them. The personnel from Terabeam arrived on 7 March to assist the students with baseline testing prior to deploying to the training area. The Elliptica link was setup at roughly 200 meters end-to-end, and a media converter was input between the link head and the network router. Multi-mode fiber cable was used from the link head to the media converter. Since the main focus of the baseline testing was to get network equipment operating properly, the Terabeam link was not tested for throughput ratings, but the link did perform flawlessly on this day.

On 8 March, Terabeam's personnel departed for the training area to set up one link at the POP and the other at MRC #1. The goal on this day was to establish connectivity between the NOC, POP, and MRC #1. The NOC to POP communications was via OFDM, and the POP to MRC #1 was via FSO. The data that was collected was very similar to what Lightpointe experienced. The OFDM link dictated the throughput from the NOC to MRC #1. Since the throughput of the OFDM was anywhere between 2-12 Mbps while established in the network, the FSO link pushed through what was coming in. Thus, the overall throughput data obtained from the NOC to MRC #1 is reported in Figure 51 below. This data was collected in Iperf.

```
------------------------------------------------------------
Client connecting to 192.168.70.5, TCP port 5001
TCP window size: 63.0 KByte (default)
------------------------------------------------------------
[928] local 192.168.20.3 port 1420 connected with 192.168.70.5 port 5001
[ ID] Interval       Transfer     Bandwidth
[928]  0.0- 5.2 sec   2.7 MBytes   4.1 Mbits/sec
[928]  5.2-10.1 sec   1.8 MBytes   2.9 Mbits/sec
[928] 10.1-15.0 sec   3.9 MBytes   6.3 Mbits/sec
[928] 15.0-20.0 sec   3.4 MBytes   5.4 Mbits/sec
[928]  0.0-20.3 sec  11.7 MBytes   4.6 Mbits/sec
```

Figure 52. IPERF DATA FROM NOC TO MRC #1 VIA OFDM AND FSO

Terabeam was set up at MRC #1 on 9 March as well. MRC site #2 was established on this date with an OFDM link connecting the site to the POP. The satellite link provided by the Segovia/Omega Systems team was interconnecting the NOC and POP site. Thus, on this day three different technologies were established in the Wide Area Network. Unfortunately, due to routing problems on the Cisco 3550 switch at the POP site, no data could be transferred to the MRC site #1.

Terabeam's support was superb throughout their three days of testing at Camp Roberts. They were able to deploy their gear throughout the training area and establish connectivity in an expedient manner.

c. fSONA

fSONA responded to a short notice request to support this testing event with their FSO technology. Pablo Bandera, Product Manager, came out from British Columbia, Canada with fSONA's SONAbeam 155-E FSO product that supports E1 to OC-3, rate-adaptive. The SONAbeam 155-E is a lightweight unit that is optimized for short-distance links from 50 meters up to 2,500 meters. It includes two redundant high-powered lasers transmitting at 1550 nanometers.[49] During this testing event, the 155-E

[49] http://www.fsona.com/product.php?sec=155e (April 2004).

sat on top of a lightweight telescopic stand. It used a single-mode fiber cable from the link head to the media converter, and then from the media converter to the network router via a CAT-5 cable. Figure 52 shows the SONAbeam 155-E.

Figure 53. fSONA's SONABEAM 155-E[50]

fSONA was integrated into the testing on March 10-11 during the communications on-the-move portion. The authors arranged to use Redline and Alvarion's OFDM link between the two vehicles in the convoy while in motion. To incorporate fSONA's equipment, each vehicle, MRC #1 and MRC #2, was equipped with a SONAbeam 155-E. After a certain amount of testing was done with OFDM, the vehicles stopped on the side of the road and attained LOS for the FSO link. This established a link between the two vehicles at about 500 meters. The goal on both days with fSONA was to use Segovia/Omega Systems' satellite link between the NOC and POP, the 802.11b signal between the POP and MRC #1 thru the tethered balloon, and finally the FSO link between MRC #1 and MRC #2.

Mr. Bandera set up the two links within 25 minutes, but then ran into trouble when connecting to the media converters. When connecting the single-mode fiber cable to the media converters, the converters did not show a link light. This happened on both days, so the goal of establishing connectivity with FSO between MRC #1 and #2 was not accomplished. See the Findings and Analysis section for further explanation.

50 http://www.fsona.com/product.php?sec=155e (May 2004).

d. 802.11a (Vehicles)

On several occasions at different sites and times, the Wireless Access Point (WAP) 55AG was used to provide a 802.11a Wireless LAN (WLAN). The computers in the WLAN were equipped with WPC55AG notebook adaptors to communicate with the access point.

The WAP55AG actually contains two separate wireless connectivity radio transceivers, which support 802.11a/b/g popular wireless networking specifications. The first transceiver uses the 2.4 GHz radio band, supporting both the widely used and inexpensive Wireless-B (802.11b) standard at 11 Mbps, and the new, almost five times faster, Wireless-G (draft 802.11g) at 54 Mbps. The second radio operates in the 5 GHz band, and supports Wireless-A (802.11a) networking, also at 54 Mbps. Since the two radios operate in different bands, they can work simultaneously, blanketing a wireless zone with high-speed bandwidth.[51]

e. Voice Over Internet Protocol (VoIP)

A mixture of Cisco 7940G, 7960G, and 7920 IP telephones were used to provide voice service throughout the network. The 7940G and 7960G phones use a simple CAT-5 cable connection, while the other end was connected to the LAN Cisco switch. The Cisco Wireless IP Phone 7920 is an easy-to-use IEEE 802.11b wireless IP phone that provided comprehensive voice communications in conjunction with Cisco's Call Manager product. At the NOC, the wireless 7920 IP telephone was utilized with a Linksys 802.11b access point attached to the LAN switch. The Call Manager server was always located at the NOC. The phones throughout the two LANs first talked to the server before making a call to another phone within the network. The server was connected to the NOC Cisco 2950 switch via CAT-5 cable. Each phone and the server was assigned its own unique IP address. Finally, each phone had a phone number assigned to it by the server. This enabled a quick call to any phone on the network.

The Voice over IP protocol employed was Cisco's Call Manager Skinny Client Control Protocol (SCCP). SCCP is a Cisco proprietary protocol used between Cisco Call Manager and Cisco Voice over IP phones. This protocol is also supported by other vendors. The Cisco IP Phones 7960G and 7940G are also capable of supporting

[51] http://www.linksys.com/products/product.asp?grid=33&scid=35&prid=538 (May 2004).

other protocols such as Session Initiated Protocol (SIP), and Media Gateway Control Protocol (MGCP). However, the students chose to use the SCCP.

Finally, the link between the NOC and POP saw no quality of service issues with VoIP, even while traversing a satellite link that was double hopping from the NOC to the POP. There was a slight delay when talking but the clarity of voices was nearly perfect. Even when communicating from the NOC to the POP via satellite link and then to MRC #1 and #2 sites via FSO or OFDM, the quality of service was not affected. Testing was not conducted evaluating VoIP when the vehicles were on the move.

2. Beyond Line-of-Sight (BLOS)

a. Alvarion

Alvarion supported this testing event from March 8-11 with Soria Constantino, Field Technician, from Carlsbad, CA. Mr. Constantino brought with him Alvarion's BreezeACCESS VL system. This system offers non-line-of-sight (NLOS) point-to-multipoint or point-to-point solutions in the 5 GHz band: 5.725-5.850 GHz and 5.47-5.725 GHz. The BreezeACCESS uses OFDM technology to overcome obstacles, such as trees, buildings, and hills for quick and effortless NLOS deployments. It can operate at speeds of 6 Mbps, 24 Mbps, and 54 Mbps. The system comes with indoor and outdoor units. The indoor unit is a lightweight, handheld device that is powered by 110V/220V AC. It has an RJ-45 port to run CAT-5 cable from the unit to a network device, such as a router for this testing event.[52] This unit is shown in Figure 53 below.

Figure 54. BREEZEACCESS VL INDOOR UNIT[53]

[52] http://www.alvarion.com/RunTime/Products_2020.asp?tNodeParam=30 (April 2004).

[53] Alvarion, "Broadband Wireless Access Brief", February 2004.

The outdoor unit consists of an antenna and radio, which is built into the antenna. The antenna can produce sector, omni-directional, or tight beam radiation patterns. There is an RJ-45 port on the outdoor unit as well, which connects to the indoor unit via a CAT-5 cable. This unit is depicted in Figure 54 below.

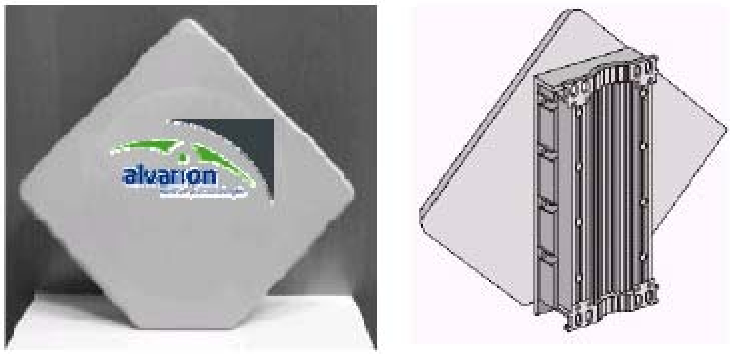

Figure 55. BREEZEACCESS VL OUTDOOR UNIT[54]

During the testing event on 8 March, Alvarion set up a point-to-point link at Camp Roberts between the NOC and POP sites. This setup was BLOS over a hill that was roughly 100-200 feet tall with trees sporadically located between the links. At the NOC site, the antenna was set on a mast that was raised to about 20 feet high. At the POP site, the antenna was also on a similar mast of 20 feet. Both of these antennas were two-foot uni-directional antennas with a 28.5 dBi gain and 3 dB beamwidth of 4.5 degrees. The data collected going from the NOC to the POP via Alvarion's link showed that 12 Mbps of data was being transferred when using Iperf (64 Kbyte size packets). When going from the NOC to the POP over Alvarion's link and then from the POP to MRC #1, where an FSO link was established, the data from Iperf (64 Kbyte size packets) showed 5.4 Mbps of throughput. Alvarion also had a program called Q-Check that ran throughput tests over the link. Q-Check is a network troubleshooting utility that checks network response time, throughput, and streaming performance.[55] This throughput data ranged between 4–12 Mbps when going from a computer on the LAN at the NOC site to a computer on the LAN at the POP site. The setup time during this day was about one

---

[54] Alvarion, "Broadband Wireless Access Brief", February 2004.

[55] http://www.ixiacom.com/products/performance_applications/pa_display.php?skey=pa_q_check (May 2004).

hour for the Alvarion link between the NOC and POP sites, but Mr. Constantino was working alone so he had to go back and forth between the two sites.

On 9 March, Alvarion deployed out to the MRC #2 and POP sites with the same equipment as the previous day. The 1,000-meter link was set up BLOS, and the terrain between the sites was hilly with numerous trees throughout the landscape. Since the focus was on establishing the network with the Cisco 3550 Switch at the POP site, the researchers did not collect data during this day. Although it took most of the day to establish a connection, by 1700 connectivity from MRC #2 over the OFDM link was solid to the POP and NOC; however, connectivity to MRC #1 was not established due to routing configuration issues at the POP switch.

Overall, Alvarion's equipment and support were solid throughout the week. The biggest consideration when using the BreezeACCESS VL is the type of antenna since there are numerous sector antennas as well as omni-directional ones. A user must evaluate the scenario to determine what type of antenna to utilize.

b. Redline Communications

This testing event was the first time the students were able to work with Redline Communications. Dave Rumore, Sales Representative, and Don Mullin, Engineer, supported this event from March 8-10. They brought with them their AN-50 OFDM system with sector, narrow beam point-to-point and omni-directional antennas. The AN-50 system operates in the license-exempt 5.8 GHz band and includes advanced technologies to address potential inter-cell interference issues. The AN-50 maximizes spectral efficiency with a unique patented bi-directional adaptive modulation technique, automatically selecting any of eight modulation schemes providing a solid connection even in challenging link conditions. Furthermore, the AN-50 delivers an over-the-air rate of up to 72 Mbps, a robust NLOS capability, and audible antenna alignment and diagnostic capabilities.[56]

The essence of OFDM is that it breaks up the transmitted signal into many smaller signals, as shown in Figure 55 below.

[56] Redline Communications, "Redline Family White Paper", October 2003.

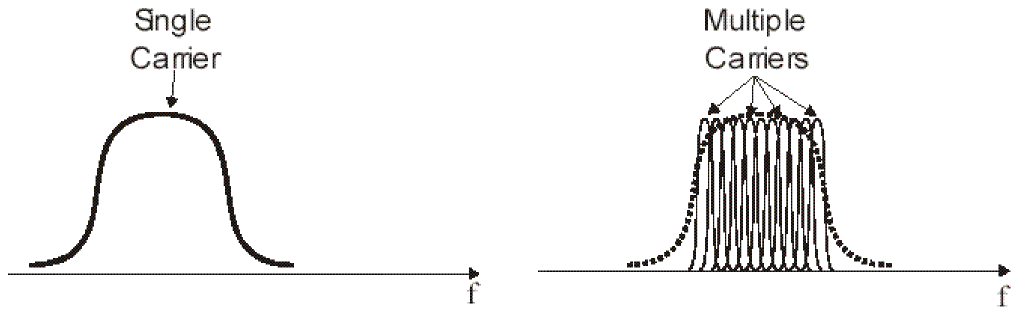

Figure 56. OFDM CARRIER BREAKDOWN[57]

For example, instead of one signal carrying 72 Mbps of data, there are 48 separate carriers, each carrying about 1.5 Mbps of data (in the case of the Redline product).

One key aspect of OFDM implementation is that the individual carriers overlap significantly to preserve overall bandwidth. Normally, overlapping signals would interfere with each other, however, through special signal processing, the carriers in an OFDM waveform are spaced in such a manner that they effectively do not see each other, i.e. they are orthogonal to each other.[58]

On 8 March, Redline set up one of their sector antennas at the NOC and the other sector antenna was placed at the POP site. A distance of 2,000 meters with a hill and sporadic trees in between separated these two sites. The set up of the link took much longer than normal due to the lack of a good azimuth between the two sites. When Redline moved from the NOC to the POP, they had a rough estimate of what the azimuth would be but this proved insufficient. After an hour, Don Mullin returned to the NOC from the POP and determined that the antenna at the NOC site was way off from where the POP site was set up. After arranging the antenna in the appropriate direction, connectivity came up right away. Once the links were configured for the network, Redline used their computers and connected them to the LAN switches at both sites. They ran their Q-Check program, which was the same utility used by Alvarion, and it produced a reading between 5-11 Mbps from one computer to the other while varying the size of the packets. Iperf then sent 64 Kbyte size packets resulting in 2.4 Mbps from

[57] Redline Communications, “Second Generation High-Capacity Broadband Wireless Solutions”, April 2003.

[58] Redline Communications, “Second Generation High-Capacity Broadband Wireless Solutions”, April 2003.

computer to computer. After a while, Redline took their computers off of the LAN and hooked them directly onto the links resulting in a reading on Q-Check of 27 Mbps. Most of the data readings varied depending on the size of the packet being pushed across the link and where the computer was connected.

One observation on 8 March was that Redline's AN-50 system was set for auto-negotiation. Nothing was done on this day to change the setting to full duplex, and all of the network equipment was set for full duplex. This could have been another reason why the readings were inconsistent. Figure 56 below shows the AN-50 system.

Figure 57. AN-50 SYSTEM

On 9 March, Redline brought their equipment out to MRC #2 and the POP. They used the same equipment as the day before with their sector antennas mounted on five-foot stands. On this day, the terrain was less conducive to establish connectivity with about 1,000 meters between the sites, due to more hills and dense tree lines. This was a good test to see if their equipment could perform as advertised. Once the equipment was aligned and set up, the link was established right away. Preparation was made ahead of time to get a good azimuth. An advantage of Redline's AN-50 system is that it has an audio tone that indicates link alignment. This greatly assists those who are establishing the link. Figure 57 below shows the terrain Redline had to traverse on this day. The data collected on 9 March from Q-Check was showing between 18-24 Mbps when going from link to link and about 14 Mbps when running it on the LAN. The throughput drop was due to the networking equipment (laptops, switches, and routers).

Figure 58. REDLINE’S ANTENNA ON 9 MARCH AT MRC #2

While experimenting on this day with the auto-negotiation on the AN-50 system, the students determined that the system would go to full duplex if a switch was placed in between the AN-50 system and the LAN router. Thus, the hookup went from the sector antenna to the AN-50 via RF cable, then from the AN-50 to the switch via CAT-5, and from the switch to the router also via CAT-5. The link also proved to be more stable on this day.

Overall, Redline Communications’ AN-50 products performed very well. They were invited by two Naval Postgraduate School professors to conduct further testing with NPS. These tests are at Camp Roberts, CA and are supported by Special Operations Command.

c. Balloon 802.11

The tethered balloon is approximately 12 feet in diameter when filled with helium. Several tanks of helium are needed for operation of the balloon, and it takes roughly an hour to completely fill the balloon. While airborne, the balloon does not perform well in high winds. If winds are over 20 mph, the balloon should not be flown to alleviate possible damage. In addition, due to the constant movement of the balloon in high winds, steady connectivity can be challenging.

The balloon can carry a payload of up to 50 pounds, which is located underneath the balloon. For the March testing, the payload was about 20 pounds and contained an omni-directional antenna, access point, 1-Watt Amplifier, DC to AC power converter, and two Lithium batteries used as the power source. A research associate at NPS, Kevin Jones, built this payload. Figure 58 below shows the actual payload with the access point and antenna located on the bottom and one lithium battery located on each side.

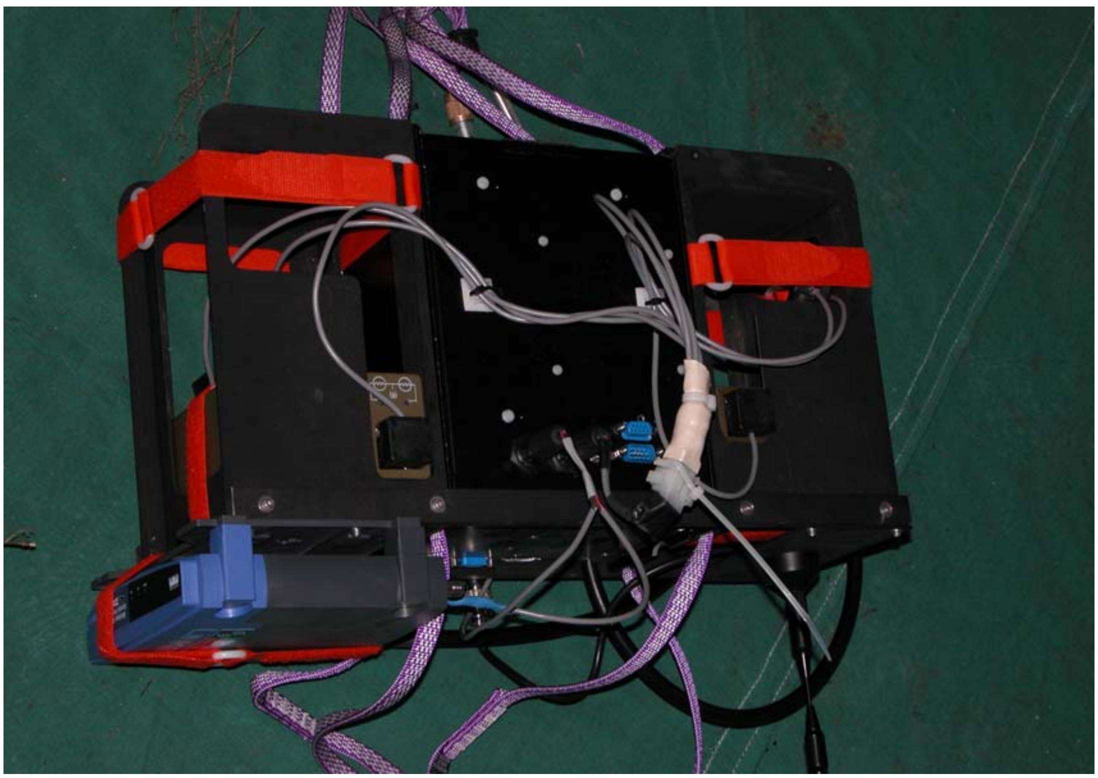

Figure 59. TETHERED BALLOON PAYLOAD

To deploy or retrieve the balloon, an attached motor controls a large reel of rope. The balloon could reach an altitude of approximately 3,000 feet. To fly the balloon, a large open area is needed because high winds can cause the balloon to be pushed in a horizontally rather than vertically. Figure 59 below shows the balloon system deployment/retrieval mechanism.

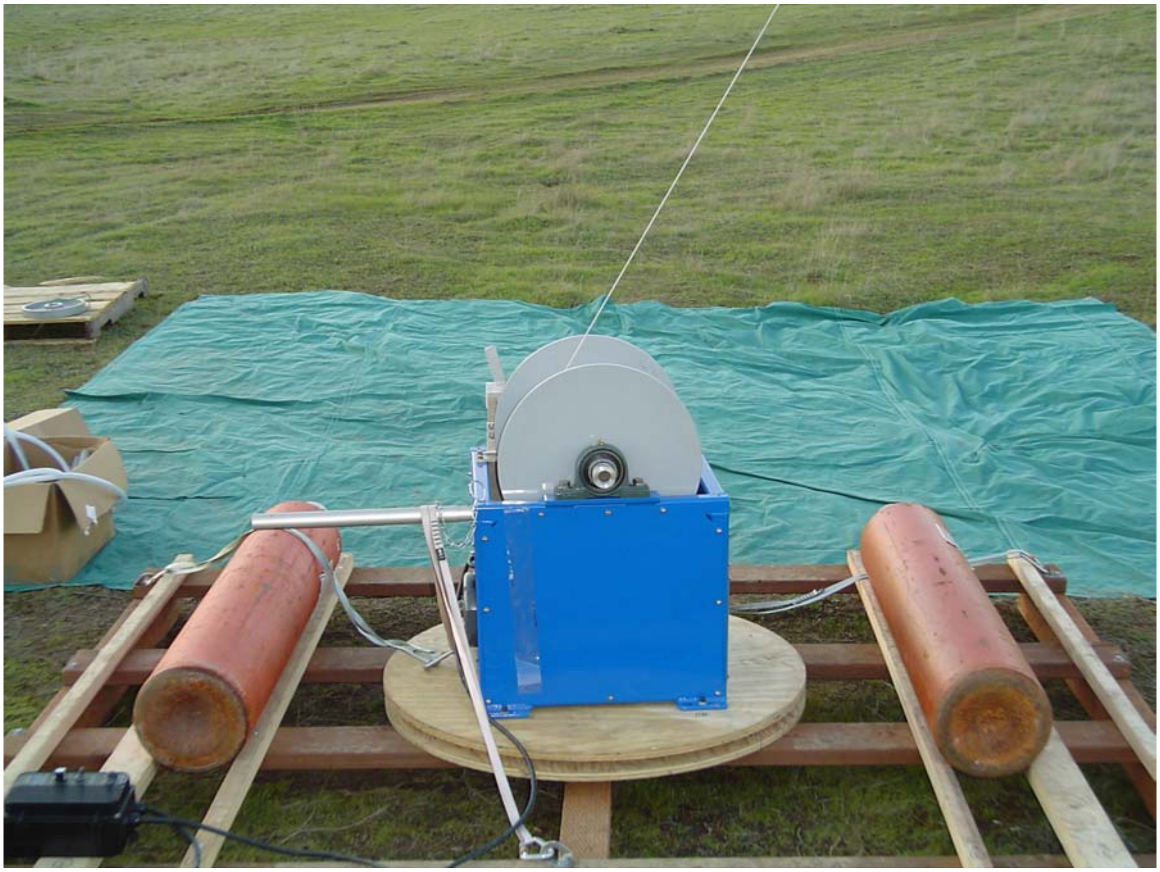

Figure 60. BASE OF THE TETHERED BALLOON

On 8 March, the tethered balloon was first launched to conduct connectivity tests that were separate from the established network. The balloon was deployed to about 800 feet and the wind was relatively calm.

The balloon's access point was a Linksys WAP11. This device was set to run in bridge mode. On this day, another WAP11 on the ground was used in bridge mode. The WAP11 has a web interface to configure the device. Entering the IP address of the access point into the URL line on Internet Explorer can access the web interface. Before doing this, the computer that is connected to the access point via CAT-5 cable must be on the same subnet as the IP address assigned to the access point. For example, if the IP address for the access point is 192.168.2.150, then the IP address for the computer configuring the access point must be 192.168.2.X. In addition, after the IP addresses are set, the Media Access Control (MAC) address from the other access point must be entered for the access point that is being configured. Furthermore, the gateway must be set to the IP address of the other access point. This had to be done for each access point on the ground as well as in the air. Figure 60 below gives an example of the Linksys web interface configuration page.

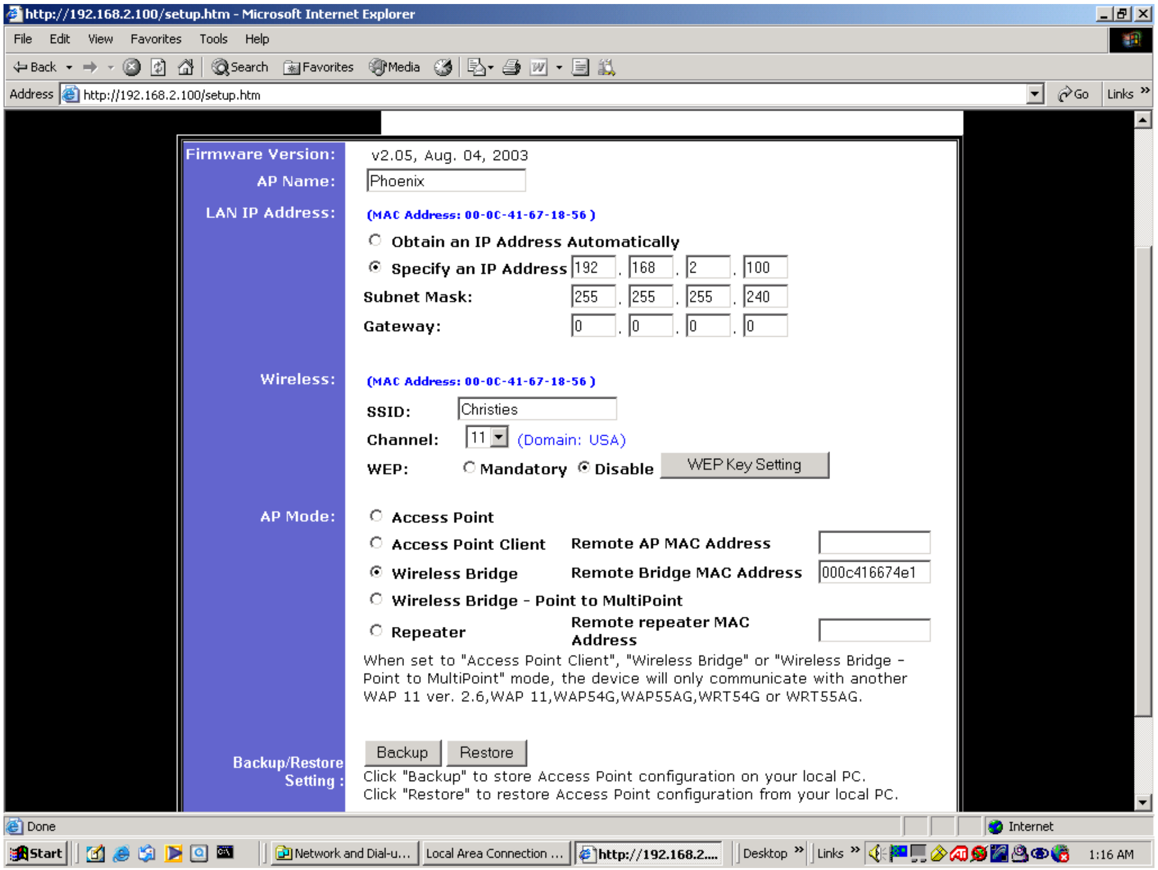

Figure 61.   WAP11 WEB INTERFACE CONFIGURATION HOMEPAGE

Overall, the initial test conducted on this day was point-to-point with both access points configured in bridge mode. The access point on the ground utilized the regular antennas that come with the device, and the access point on the balloon was outfitted with an omni-directional antenna with a 5 dB gain. A continuous ping confirmed proper connectivity between the two sites. There was a 95% or better success rate over a 15-minute period.

On 9 March, the balloon was launched in order to provide connectivity between the NOC and POP. Due to the testing of the satellite link between the two sites, time was limited to establish connectivity through the balloon. Both the POP and NOC had LOS with the balloon, but the NOC and POP were BLOS.

In order to attempt to establish connectivity from the NOC to the POP via the tethered balloon, special settings needed to be placed on the WAP11s. Again, WAP11s were used at the NOC, POP, and on the balloon. Each site had omni-directional antennas with a 5 dB gain. The WAP11 on the balloon was set for bridge mode but in point-to-multipoint mode. No MAC address or gateway IP address was necessary for this configuration. At the NOC, the configuration was set for bridge mode with a remote MAC address of the access point on the balloon, and the gateway was set for the IP address of the balloon's access point. At the POP, the configuration was the same as the NOC. Finally, the same channel and Service Set Identifier (SSID) were set for all three WAP11s.

The students were unable to establish connectivity between the NOC and the POP on 9 March. The students believed this was due to the position of the omni-directional antenna on-board the balloon. See the communications on-the-move section below for information on the tethered balloon relay.

d. Unmanned Aerial Vehicle (UAV) 802.11b

MLB Company of Mountain View, CA supported this testing event from March 9-11 with their "Volcano" UAV platform. The 55-pound Volcano aircraft is designed to carry a 15 lb payload up to an altitude of 12,000 feet. A 50 cc 2-stroke gasoline engine was customized for this aircraft, and it has an endurance of 2 hours at 40 miles per hour. Furthermore, the Volcano's flight control is done via autonomous waypoint navigation or direct radio control uplink. The Volcano UAV has been actively flying since December 2002.[59] Figure 61 shows the Volcano aircraft.

59 http://www.spyplanes.com/volcano.html (May 2004).

Figure 62. STEPHEN MORRIS AND MLB'S VOLCANO UAV

This platform was utilized for communications relay during the testing event for nodes scattered throughout the training area. Kevin Jones from NPS built a wooden platform that was placed underneath the UAV. It contained the following: omni-directional antenna, Linksys access point, 1-Watt amplifier, DC to AC power converter, and one lithium battery. The omni-directional antenna pointed down through the wooden platform. This platform weighed about seven pounds and was attached to the UAV via three metal clipped straps that wrapped around the UAV and the platform. Figure 62 shows the platform attached to the UAV.

Figure 63. MLB VOLCANO UAV WITH PAYLOAD

On 9 March, Stephen Morris, President of MLB, and Hank Jones arrived with the Volcano and conducted familiarization flights along with some initial on-board communications tests. After these flights and tests, the wooden platform was mounted on the UAV. The aircraft was controlled with a handheld device by Mr. Morris to maneuver on the runway and take off. Only 500 meters of runway was needed to get the aircraft off the ground. After the UAV entered its flight pattern, which was programmed into the computer system that goes along with the aircraft, the students started to conduct communications testing with the aerial platform.

The computer system and antenna used to control the Volcano can be seen in Figure 63. The frequency to control the aircraft was 900 MHz and the on-board camera used the 2.4 GHz band to transmit live video back to the ground control station. In the computer software program that was utilized to control the aircraft while in flight, waypoints and altitude information were entered onto a digital map of the desired flight pattern of the aircraft. Thus, as long as the ground antenna had LOS with the aircraft no manual movement with the handheld device was required while the aircraft was in flight.

Consequently, the software allowed the user to view the exact pattern of the entire flight on a digital map after mission completion.

Figure 64. MLB FLIGHT CONTROL GEAR FOR VOLCANO

During the flight on 9 March, 802.11b connectivity was attempted from the NOC to the POP via the UAV. Linksys WAP11 Access Points were used at each site and omni-directional antennas with 5 dB gain and 1-Watt amplifiers were employed with the access points. The setup of the access points was the exact same as the configuration explained in the tethered balloon section. The ground access points were set for point-to-point in bridge mode with the MAC address of the access point on the UAV and a gateway IP address of the UAV's access point. The airborne access point was set on point-to-multipoint with no gateway IP address. Unfortunately, very few pings were attained during ping connectivity testing on this day with the existing antennas, despite the UAV's altitude of 500 feet and flying directly between both the NOC and POP. Upon further research, the students determined that the omni-directional antenna on the

UAV was not positioned very well. More success would have been attained with the antenna by placing it on the aircraft in a position that allows for the most optimal radiation pattern.

e. NetMeeting

NetMeeting is a Microsoft Windows product that delivers an open, extensible platform for real-time communications, offering audio, video, and data conferencing functionality.

During this testing event, the students utilized NetMeeting as a tool to transmit live video between the sites via Logitech cameras set up in each LAN, to talk via headsets hooked up to the computer, and to perform data messaging between users at all sites. On 11 March, MRC #2 was able to see video in NetMeeting after traversing a satellite link, 802.11b through the tethered balloon, and OFDM from the NOC.

f. VoIP

See the LOS section for VoIP explanation during the testing event. No direct testing was done with VoIP when traversing solely BLOS technology (OFDM, tethered balloon, or UAV). Instead, IP phones were employed through a multitude of technologies. For example on 9 March, when MRC #2 wanted to talk to the NOC over the IP phone, the phone would first communicate with the Call Manager server over OFDM and then through the broadband satellite link resulting in a successful phone connection. There was a slight delay when talking through these means but the quality of service was not affected. However, when making a phone call on 11 March from MRC #1 through the tethered balloon to the POP and then to the NOC via satellite, there were quality of service issues as the link between MRC #1 and the POP over the balloon was experiencing more than 20% packet loss. The phone would occasionally lose connectivity due to this packet loss.

3. Over-the-Horizon (OTH)

a. Segovia/Omega Systems

Segovia and Omega Systems supported this exercise from March 7-11 with Jeff Howard, Sales Director, and Ross Warren, Senior Sales Engineer, from Segovia and Matt Jones, Vice President Business Development, from Omega Systems. Segovia is the service provider of the satellite system and Omega Systems produces the satellite dishes. During this event, a one-meter satellite ground terminal was utilized at the NOC, and a mounted one-meter satellite terminal on a Sports Utility Vehicle was employed at the POP. The ground terminal is a multiple case system that is powered by a 110V source, and its transmitting frequency is between 13.75–14.50 GHz with a receiving frequency between 11.70–12.75 GHz. This satellite dish is manually pointed at the satellite for connectivity. Figure 64 below shows the ground terminal in the foreground.

Figure 65. SEGOVIA/OMEGA SYSTEMS GROUND TERMINAL

The mounted terminal requires the same power load and it operates in the same frequency band. However, it automatically aligns itself to the satellite once it is turned on. This yields for a quick setup time and operations of the equipment can begin within minutes. Figure 65 illustrates the mounted satellite terminal.

Figure 66. OMEGA SYSTEMS MOUNTED SATELLITE TERMINAL

Both terminals are capable of Type 1 encryption to provide for a secure satellite connection, and the throughput for the services can range from 128 Kbps to 9 Mbps.

During this testing event, the personnel from Segovia and Omega Systems demonstrated their flexibility with the setup of the terminals and the services that they provided. Segovia's Ross Warren was able to coordinate with his headquarters in order to arrange for the airborne satellite to act as a retransmission site for the link between the NOC and the POP (The satellite link was double-hopping between the NOC and POP). See Figure 66 below for latency between the NOC and POP. From the table, one can see the time is roughly one second to ping between the two sites. By comparison, within a LAN two computers can ping each other with a time of less than 10 milliseconds.

```
Reply from 192.168.5.20: bytes=32 time=1032ms TTL=123
Reply from 192.168.5.20: bytes=32 time=1011ms TTL=123
Reply from 192.168.5.20: bytes=32 time=1012ms TTL=123
Reply from 192.168.5.20: bytes=32 time=1021ms TTL=123

Ping statistics for 192.168.5.20:
   Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
   Minimum = 1011ms, Maximum =  1032ms, Average =  1019ms
```

Figure 67. LATENCY DATA WITH SEGOVIA LINK

The satellite services of Segovia were only intended to be used for retransmission, not for Internet connectivity or to provide phone services. Even though Segovia would have been able to arrange Internet services with a retransmission capability, the students did not pursue this option. Not only did Mr. Warren provide customer support for his equipment, but he also went above and beyond by assisting the students with the configuration of the entire network of routers, switches, access points, and IP phones.

On 7 March, Segovia established their satellite links and became familiar with the entire network setup. They had to configure their gear appropriately to plug-and-play with CAT-5 cable from their system into the established network router.

The next day (8 March), Segovia spent the morning arranging with their headquarters to retransmit the signal between the NOC and POP. In the late afternoon, after OFDM testing was complete between the NOC and POP, Segovia successfully tested their setup while connected to the network.

On 9 March, Segovia established their link for the entire day with the ground terminal at the NOC and the mounted dish at the POP. They had their settings for bandwidth set very low, which was not even close to their maximum capabilities of 9 Mbps. Figure 67 below shows the Iperf test conducted on the link between the NOC and POP with 64 Kbyte size packets flooding the link.

```
-----------------------------------------------------------
Client connecting to 192.168.5.5, TCP port 5001
TCP window size: 63.0 KByte (default)
-----------------------------------------------------------
[928] local 192.168.20.3 port 1433 connected with 192.168.5.5 port 5001
[ ID] Interval          Transfer       Bandwidth
[928]  0.0- 5.1 sec     192 KBytes     298 Kbits/sec
[928]  5.1-10.6 sec     40.0 KBytes    59.1 Kbits/sec
[928] 10.6-16.0 sec     40.0 KBytes    59.4 Kbits/sec
[928] 16.0-20.1 sec     32.0 KBytes    62.2 Kbits/sec
[928]  0.0-23.3 sec     304 KBytes     104 Kbits/sec
```

Figure 68. IPERF DATA ON 9 MARCH FROM SEGOVIA'S LINK

After Segovia arranged for their bandwidth capabilities to be much higher on 10 March, Iperf data was much more consistent and higher. The first test conducted was with Iperf when no IP phone traffic or data was being sent from the NOC to the POP. Figure 68 shows this data.

```
-----------------------------------------------------------
Client connecting to 192.168.5.20, TCP port 5001
TCP window size: 63.0 KByte (default)
-----------------------------------------------------------
[928] local 192.168.20.3 port 1049 connected with 192.168.5.20 port
5001
[ ID] Interval          Transfer       Bandwidth
[928]  0.0- 5.1 sec     640 KBytes     1.0 Mbits/sec
[928]  5.1-10.1 sec     616 KBytes     986 Kbits/sec
[928] 10.1-15.1 sec     632 KBytes     996 Kbits/sec
[928] 15.1-20.1 sec     608 KBytes     987 Kbits/sec
[928]  0.0-22.3 sec     2.4 MBytes     897 Kbits/sec
```

Figure 69. IPERF DATA ON 10 MARCH WITH SEGOVIA'S LINK

After this was complete, data was collected with Iperf on the satellite link when a Cisco IP Phone was utilized to place a call between the NOC and POP (This was a phone call placed by using VoIP within the network not Segovia's phone services). When the Iperf packets flooded the network, the IP phone started experiencing a one to two second delay, but voice quality was still excellent. However, it became evident that the bandwidth would drop considerably when a phone call took place. Figure 69 below illustrates the data collected.

```
------------------------------------------------------------
Client connecting to 192.168.5.20, TCP port 5001
TCP window size: 63.0 KByte (default)
------------------------------------------------------------
[928] local 192.168.20.3 port 1052 connected with 192.168.5.20 port 5001
[ ID] Interval       Transfer     Bandwidth
[928]  0.0- 5.2 sec   184 KBytes   282 Kbits/sec
[928]  5.2-10.7 sec  40.0 KBytes  58.1 Kbits/sec
[928] 10.7-15.1 sec  32.0 KBytes  58.9 Kbits/sec
[928] 15.1-20.6 sec  40.0 KBytes  58.1 Kbits/sec
[928] 20.6-25.8 sec  40.0 KBytes  61.6 Kbits/sec
[928] 25.8-31.1 sec  40.0 KBytes  60.0 Kbits/sec
[928] 31.1-35.3 sec  32.0 KBytes  61.3 Kbits/sec
[928] 35.3-40.6 sec  40.0 KBytes  60.3 Kbits/sec
[928] 40.6-45.5 sec  48.0 KBytes  78.6 Kbits/sec
[928] 45.5-50.3 sec   152 KBytes   252 Kbits/sec
[928] 50.3-55.3 sec  40.0 KBytes  63.8 Kbits/sec
[928] 55.3-60.9 sec  40.0 KBytes  57.4 Kbits/sec
[928] 60.9-65.0 sec  32.0 KBytes  62.3 Kbits/sec
[928] 65.0-70.2 sec  40.0 KBytes  61.6 Kbits/sec
[928] 70.2-75.8 sec  40.0 KBytes  57.2 Kbits/sec
[928] 75.8-80.1 sec  32.0 KBytes  59.2 Kbits/sec
[928] 80.1-85.1 sec  40.0 KBytes  64.2 Kbits/sec
[928] 85.1-90.8 sec   192 KBytes   270 Kbits/sec
[928] 90.8-95.2 sec  32.0 KBytes  58.8 Kbits/sec
[928] 95.2-100.3 sec  40.0 KBytes  62.3 Kbits/sec
[ ID] Interval       Transfer     Bandwidth
[928]  0.0-103.2 sec  1.1 MBytes  91.1 Kbits/sec
```

Figure 70. SEGOVIA IPERF DATA ON 10 MARCH WITH IP PHONE

The last day of the testing was a complete success as Segovia's link provided a stable connection between the NOC and POP as the students worked to establish 802.11b through a tethered balloon and OFDM on-the-move throughout the rest of the network.

Overall, Segovia and Omega Systems provided a solid satellite link with less than 10 minutes of down time throughout the week. They proved their versatility by being able to use the satellite as a retransmission device within a private network. Normally, they are an Internet and phone services provider. Furthermore, the mounted terminal proved to be a package that Marines could utilize with a mobile unit. With its self-acquiring capabilities, the unit can be up and running within minutes. Omega is also working on a package that can communicate while on the move.

b. Nera

Nera supported this exercise from March 9-11 with Torgrim Jorgensen, Senior Sales from the Norway office, and Peter Coffman, Sales Director out of the Texas office. Nera's NWC Voyager system, INMARSAT capabilities on-the-move, was utilized in the convoy on 11 March. In addition, Nera's World Communicator was demonstrated on 10 March but not used as planned during this testing evolution. See the Appendix for further explanation of the NWC Voyage and World Communicator.

During this testing, the NWC Voyager was mounted on a custom built wood platform in the back of a pickup truck. The platform was specifically built so that the satellite antenna would clear the bed of the truck. Figure 70 below shows this set up.

Figure 71. NERA INMARSAT MOUNTED ON VEHICLE PLATFORM

The objective for the Nera satellite system during this event was to bounce the signal between the Voyager at MRC #1 and the World Communicator at the NOC, much like what Segovia/Omega Systems did with their satellite link. This would be the WAN connection between the two LANs. The NWC Voyager on MRC #1 would provide connectivity for the entire convoy to talk back to the NOC since there was an OFDM link between the vehicles. Then, the NOC would communicate with the POP via Segovia's satellite link to complete the connectivity between all nodes. However, after two days of working on the above configuration it was determined that this setup could not be accomplished with the available gear that Nera had on hand.

In order to test the capabilities of Nera's system, the students employed the Internet and phone connectivity capabilities in MRC #1 with the Voyager system. A phone was connected to the modem in MRC #1 and another cellular phone was placed at the NOC. MRC #1 was also equipped with a laptop that connected to the Voyager modem, which provided Internet connectivity. Figure 71 below shows the phone and modem. While MRC #1 was in motion with the mounted Voyager, phone calls and most file downloads were performed without error. When the look angle of the Voyager was blocked by hills next to the vehicle, the download capabilities were temporarily terminated.

Figure 72. NERA'S PHONE AND MODEM

During the first phone call between MRC #1 and the NOC, a 4.6 Kbps rate was used. However, during the second phone call, a 64 Kbps rate was used and the voice quality was much better. Neither of the rates produced any noticeable time delay during the phone call. File downloads were conducted for demonstration of the Internet connectivity. First, a 1.2 Mbyte file took 11 minutes and 35 seconds to download. Next, a 2.8 Mbyte file took 16 minutes and 32 seconds to download. Since the link between MRC #1 and the NOC with Nera's equipment could not be accomplished, the World Communicator was not used.

Overall, Nera was able to demonstrate their capabilities on the move. The Nera representative did explain that they could make the configuration work that was originally intended if they had the appropriate equipment. This LAN-to-LAN connectivity would have shown the ability to maintain connectivity while on the move. A scenario that this is applicable to is when main and forward command posts echelon, which usually causes them to lose most of their data capabilities, but with INMARSAT these command posts could continue to exchange desired data.

c. VoIP

Within the LOS section, VoIP is explained in greater detail. One of the main objectives for the VoIP element was to determine if there was any quality of service issues over a satellite link. The link between the NOC and POP was a Segovia/Omega System satellite service, and there was no quality of service issues with VoIP, despite this link traversing two hops from the NOC to the POP. There was a slight delay when talking but the clarity of voices was near perfect. Finally, several IP phone calls could have overloaded the satellite link's throughput of 1 Mbps and caused a quality of service issue.

4. Communications on-the-Move

a. OFDM

(1) Redline Communications. On 10 March, Redline's equipment was deployed on-the-move. The sector antennas were placed on five-foot stands mounted on a wooden platform in the vehicles. The sector antennas had 60-degree beamwidth and the other was a tighter beam of 5-degrees. The AN-50 system was placed within the bed of the pick-up trucks. The goal of the on-the-move portion was to maintain connectivity via OFDM while the two convoy vehicles were BLOS. As the vehicles started in motion, both MRC #1 and #2 established a continuous ping test. This enabled the students to see how well the link maintained connectivity. The results were favorable since connectivity was seldom lost and only for seconds when vehicles turned corners or when a hill interfered. This was also being done with sector antennas, so this could have played a role in the degraded connectivity. At the end of the day, Redline established an omni-directional antenna with a sector antenna to ensure that connectivity was maintained. This also worked and may be a better solution if the omni-directional antenna has enough gain to meet the distance of the convoy. Figure 72 below shows Redline's setup for the communications on-the-move.

Figure 73. REDLINE ON-THE-MOVE SETUP ON BOTH VEHICLES

(2) Alvarion. Because of a lack of time, Alvarion did not deploy their system on-board MRC #1 and #2 on 10 March while communications on-the-move were being evaluated. However, Mr. Constantino attempted to use Alvarion's 802.11b omni-directional system to establish connectivity with the UAV while it was airborne. Unfortunately, the UAV had a Linksys AP on-board which was not compatible with any other type of equipment.

On 11 March, Alvarion's equipment was employed on MRC #1 and #2 to establish connectivity between the vehicles while on-the-move. One vehicle employed an AU-VL 5.8 GHz Omni antenna with an 8 dB gain. The other vehicle utilized a SU-VL integrated antenna with a 10-degree beam width. The integrated antenna had a 21 dB gain. While on the move and with the vehicles BLOS of each other, the OFDM link was stable as both vehicles were continuously pinging each other. There were a couple of areas where connectivity was lost between the vehicles. This mostly occurred as one vehicle would turn a corner and get a hill between the two vehicles. The lapse of coverage only happened momentarily as the link reestablished itself. No data was collected using Iperf or Q-Check. Figure 73 below shows the antenna setup on the convoy vehicles. The antennas were mounted on a pole that was attached to a tripod. The tripod was then bolted down to a wooden platform in the bed of the truck.

Figure 74. ALVARION ANTENNA SETUP ON POLE

b. 802.11b (balloon)

On 10 March the lead vehicle in the convoy, MRC #1, was equipped with an omni-directional antenna. Connectivity was attempted between MRC #1 and the POP site via the tethered balloon. The setup of the WAP11s at MRC #1, POP, and the balloon were the exact same as explained above in the BLOS section. When attempting the relay from the NOC to the POP on 9 March, again connectivity could not be established between the two nodes. Ping tests were being done that showed the lack of connectivity.

Next, MRC #1 reconfigured the WAP-11 in order to establish connectivity with the tethered balloon directly while stopped on the side of the road. Again, the configuration was similar to what was set up on 8 March between the NOC and the tethered balloon. This time MRC #1 used a Yagi directional antenna with a beamwidth of 30 degrees and gain of 14.5 dB. And for the first time, successful pings were established between the two nodes. After this was accomplished, both MRC #1 and the POP utilized the same Yagi antennas and intermittent connectivity was attained between the two sites via the balloon. This day was fairly windy, so the balloon was moving quite a bit while deployed to 1,000 feet. When conducting ping tests between the POP and MRC #1, a 50% packet loss was recorded.

A calm day on 11 March proved to be more suitable for the deployment of the balloon as results showed much more stable connectivity. The same setup was employed as on 10 March with MRC #1 and the POP using Yagi antennas connected to the WAP11s and MRC #1 stationary. The reason for testing while stationary was that the Yagi antenna needed to be placed on a mount to maintain connectivity with the balloon. If the vehicle was moving, the antenna would have been required to be manually pointed at the balloon. A tracking antenna on the ground would be much more suitable for this type of operation.

c. 802.11b (UAV)

On 10 March, MRC #1 was equipped with a Linksys WAP11 and an omni-directional antenna with a 1-Watt amplifier. Connectivity was attempted from MRC #1 on the move with the NOC through the Volcano UAV. The UAV was flying at 500 feet between the two sites and within LOS. The students were unable to establish connectivity while pinging from the NOC to MRC #1. Next, the convoy of vehicles stopped and MRC #1 set up a Yagi antenna with 14.5 dBi gain and configured the access point to go point-to-point with the airborne access point. The UAV landed and the access point was also reconfigured for point-to-point with MRC #1. After reestablishing its track at 500 feet, MRC #1 tracked the UAV manually with the Yagi antenna and started to see better connectivity. Eighteen of 22 pings were successful. The UAV went up to 1,000 feet and the ping ratio decreased to two of 20 successful pings. At 800 feet, the ratio was six of 20 pings. With the lack of communications relay on this day, the UAV platform was never integrated into the wide area network.

Testing the next day resulted in little change as far as retransmission. Connectivity was attempted from the NOC to the POP once again but this time the POP had a Yagi antenna tracking the UAV. No successful pings were attained even while as low as 400 feet. Figure 74 below illustrates the view of the UAV looking down on the POP site. As mentioned earlier, the omni-directional antennas needed to be better placed on the aircraft to allow the radiation pattern of the antenna to emit its proper signature.

Figure 75. UAV LOOKING DOWN ON POP SITE ON 11 MARCH

Overall, MLB Company remained flexible throughout the three days of testing. They flew at varying altitudes and changed course numerous times to meet the needs of the experiment. They were able to provide the support the students expected, but prior testing needed to be done to test the antenna set up.

d. 802.11a (vehicles)

The Wireless 802.11a LAN in the moving vehicles on March 10-11 was especially helpful as the networking equipment (routers, switches, access point) were all located in the bed of the pick-up trucks. The operator with the laptop was located in the passenger side of the vehicle. Therefore, the operator did not have to run a cable between the bed of the truck and the cab. Tests were not conducted to determine the actual throughput of the 802.11a link.

This field-testing event proved very challenging due to the complexity of the network and the numerous moving parts. However, after battling through the issues that came up, the network communications architecture that was desired for CoNDOR was accomplished on the last day. Figure 75 shows the connectivity between the NOC and MRC #2. The ping test went through three different technologies: satellite link, 802.11b retransmitted through a tethered balloon, and OFDM.

```
From .20.3 to .80.3:
Pinging 192.168.80.3 with 32 bytes of data:

Reply from 192.168.80.3: bytes=32 time=1031ms TTL=120
Reply from 192.168.80.3: bytes=32 time=1052ms TTL=120
Reply from 192.168.80.3: bytes=32 time=1051ms TTL=120
Request timed out.
Reply from 192.168.80.3: bytes=32 time=1041ms TTL=120
Reply from 192.168.80.3: bytes=32 time=1072ms TTL=120
Reply from 192.168.80.3: bytes=32 time=1032ms TTL=120
Reply from 192.168.80.3: bytes=32 time=1081ms TTL=120
Reply from 192.168.80.3: bytes=32 time=1062ms TTL=120
Request timed out.
Request timed out.

Ping statistics for 192.168.80.3:
    Packets: Sent = 11, Received = 8, Lost = 3 (27% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1031ms, Maximum =  1081ms, Average =  765ms
```

Figure 76. PING TEST FROM NOC TO MRC #2

In this testing evolution, the students were able to show that multiple technologies can be employed in a WAN as long as everything is IP based and the appropriate routing schemes are employed.

THIS PAGE INTENTIONALLY LEFT BLANK

III. FINDINGS AND ANALYSIS OF EACH TESTING EVENT

A. FIELD TEST #1 (FORT ORD AND BIG SUR, CA)

1. Findings

The findings discovered during this testing event are discussed chronologically. The chronological order consists of testing with fSONA and Lightpointe's FSO products, RF and FSO employed together, data transfer time latency tests, throughput analysis when covering lasers on link head, and 802.11b with Linksys WAP11s.

During the fSONA free space optics equipment tests, a maximum throughput with fSONA's link was roughly 13 Mbps when sending files across the network from one laptop computer in one local area network (LAN) to another laptop in a second LAN. Although the ports on the switches were capable of 100 Mbps, the authors concluded that the configuration of the routers and switches in the network caused the degradation in throughput. In a configuration where the authors bypassed the routers and switches, going from one laptop connected to the FSO link to another laptop on the other end, the authors determined by using IPERF software that the link could support up to 50 Mbps. The lesson learned during this phase of the experiment was that the computer's network interface card, routers, and switches in both local area networks would need to be configured at 100 Mbps full duplex. This configuration standard for both local area networks was therefore set for follow-on experiments.

Three tests were conducted with Lightpointe equipment. One test involved determining whether a Cisco 2950 switch was capable of handling RF and FSO simultaneously. Another test with Lightpointe gear measured the time latency of the laser product by transferring data files across the network while measuring throughput across the network. The final test involved covering sectors on the laser optic and measuring the throughput in order to determine whether this type of test would be beneficial for further testing.

The authors revealed that the Cisco switch was not able to dynamically switch between RF and FSO while both links were attached to the switch. This Cisco 2950 switch was not designed to accept two different types of media. In addition, this particular switch was not configured to take the higher throughput. After reconfiguring the switch to accept FSO only, the authors were able to achieve 10 Mbps higher readings between sites. Furthermore, the authors were able to achieve a throughput of 45 Mbps after doing a quick optimization of routers and switches. The lesson learned was that the equipment being used should be configured to handle the maximum throughput. In addition, the equipment should be configured for maximum throughput in the lab instead of in the field in order to maximize experimental time in the field.

The second test was the time latency test. Data files were transferred from one local area network to another and the time to transfer files across the network was measured. The results indicated that the time annotated (actual time for the data to traverse from one network to another) was not the same as the expected time for the data to traverse across the network. For example, expected time to transfer a 100 Mbyte file over a 50 Mbps link should be 2 seconds. The reason for the difference in time is that other factors are involved when data is transferred from one laptop in one local area network to another. Some of these factors include the buffer size of the receiving and sending computers (the sending and receiving computer's buffer size temporarily stores the amount of data that is going to be sent); the processing speed of the computer sending or receiving the data; the type of file being transferred; the quality of service that is taking place within the TCP flow control (TCP uses a credit allocation scheme); and the time delta (time delta is the change in time that it takes to start the stop watch and for the actual time for the experiment to start). The lesson learned was to always be cognizant of factors outside the scope of the experiment that may affect the results obtained.

The third test involved a measure of throughput while covering certain sectors of Lightpointe's link head. During this test, sectors on the laser were covered with a cardboard box. The throughput was measured to see if covering the laser's link head had any effect on the throughput. The results indicated that the throughput remained consistent at its maximum value (45 Mbps) regardless of the sector covered. Finally, the entire link head was covered to break its signal. It took a 20-second time interval to reacquire the signal after the link head was uncovered. Twenty seconds was the time the Cisco products needed in order to recognize devices across the network, meaning the laser product was not the reason for the delay. The lesson learned was that no matter how much of the link head was covered the laser was still able to transfer data between the two sites at the same rate until the link head was completely covered.

The last item tested for the Big Sur experiment was 802.11b with a Linksys Access Point (AP-WAP 11). The purpose of this experiment was to measure the throughput of 802.11b with yagi and parabolic antennas (see Chapter 1 for specifications). The antennas were connected to the access points, which were configured in bridge mode. The results indicated that the parabolic antenna had better results when compared to the yagi antenna. In addition, NetMeeting was tested in an attempt to share files between the two local area networks. It was determined that NetMeeting had a maximum throughput limit of 1.27 Mbps. The lesson learned was that the parabolic antenna was capable of greater throughput over a longer distance (characteristics of the antenna). In addition, the maximum amount of throughput that can be transmitted when using NetMeeting is 1.27 Mbps.

2. Analysis

The analysis for this field test was a straightforward observation of ensuring that the test bed was configured for maximum throughput. The configuration for the test bed items such as routers, switches, and laptops were configured at full duplex, speed 100 Mbps. In addition, an understanding of equipment characteristics, such as TCP flow control between computers and router and switch configurations, were vital in obtaining the results. Field Test One was a basic "kick the tire" exercise (familiarization exercise) that proved to be very valuable in subsequent experiments.

B. FIELD TEST #2 (GENERAL DYNAMICS)

The findings discovered during the General Dynamics testing event are discussed below. General topics such as SolarWinds and Iperf differences and throughput testing from computer to computer are first discussed. Then, the findings for following products are mentioned: 802.11b over SecNet-11, Radio Frequency Module (RFM), Cisco Gigabit Interface Cards (GBICs), MRV, Lightpointe, Ensemble, Digital Switch Unit, KG-235, and Iridium Inverse Multiplexer (IMUX).

1. Findings

In order to accurately measure the throughput of the different technologies used to connect the two LANs, the authors utilized programs called SolarWinds and Iperf. They were significantly different in their capabilities since SolarWinds is a tool to measure throughput within a network and Iperf is used to generate data and then measure the throughput. In order to generate data traffic for SolarWinds to measure throughput, the authors used Windows file sharing between computers where various types and sizes of files were sent. This type of traffic generation varied considerably from the specific size packets that Iperf generated. Due to the difference in traffic generation between the two programs, each program provided different throughput readings. This was done intentionally.

On another aspect of throughput testing, the authors noticed that sending data from computer to computer on different LANs was significantly slower than sending data between computers that were directly connected to the link technology product, such as FSO. The traffic generated within the LAN was more realistic and thus was the preferred choice, since it would be rare to directly connect a computer to the link technology product.

The first technology tested was 802.11b over SecNet-11. Once all the equipment was set up and data was transferred between the two LANs, a noticeable difference was found when transferring data from the 192.168.3.x network to the 192.168.1.x network compared to transferring data from the 192.168.1.x to 192.168.3.x network. The throughput from the .3 to the .1 network was 1.1 Mbps and from the .1 to the .3 network it was 500 Kbps. These tests were done independently from one another, so data was not transferred both ways simultaneously. The packet loss when transmitting data was 10 to 15% throughout all the different test readings. This was quite high for a short distance of 500 meters and for high gain antennas.

Next, testing was conducted with a SecNet-11 access point placed in the Mobile Research Facility's (MRF) LAN. The access point was connected to the Cisco 2950 switch via CAT-5 cable. Data was collected when transferring files between two wireless laptops in the LAN associated with the SecNet-11 access point. In addition, data was obtained when transferring files between one wireless computer associated with the access point and one computer connected to the LAN switch. There was considerable difference in the data throughput as the wireless-to-wireless test produced a throughput of 2.3 Mbps, and the wireless-to-wired test produced a throughput of 4.5 Mbps.

The GDDS RFM product came with a Cisco 2950 switch in the carrying case. This device interacted with the local equipment and the established network. The ports on the switch were automatically set for auto-negotiation, but an assumption can't be made that CAT-5 coming off this switch can plug-and-play with any network. Consideration needs to be given to the speed and type of transmission, which need to be set on each port in order to successfully attain the highest throughput of the RFM product. When the ports on the RFM switch were not set appropriately, the average throughput measured in Iperf was 27.4 Mbps. After the ports were configured correctly to match the existing network, the throughput measured 52.3 Mbps.

When the authors originally requested a temporary loan of Cisco 3745 routers, they requested GBICs to insert into the router cards, which enabled a fiber connection from the FSO products. fSONA was the first FSO company to set up their product, so they ran their single-mode fiber cable into the GBIC on the router. The physical connection was appropriate as the cable and port were both Subscription Channel Connector (SC) capable. However, a link light was not showing on the router card. Since fSONA uses a wavelength of 1550 nanometers for their lasers and single-mode fiber to come off of the link head, they needed a GBIC that supported a 1310 nanometers wavelength and the single-mode fiber. As the authors researched the Cisco GBICs, they found that they possessed only 1000BASE-SX GBICs, which accept a wavelength of 850 nanometers and multi-mode fiber. This proved to be the reason why fSONA could not connect their link head directly with the network router via a fiber cable. fSONA needed the Cisco 1000BASE-ZX GBIC. After this failed connection, fSONA used their media converters to connect to the network with a CAT-5 cable and experienced 56 Mbps of throughput measured by SolarWinds.

MRV Communications also utilized their own media converters to convert their FSO product to the network router. Their product utilized the 850 nanometers wavelength range but no attempts were made to go directly to the router from their link head. The use of the media converter enabled MRV to come off their link head with fiber cable and connect to the router with a CAT-5 cable. MRV's throughput data readings were inconsistent between 15-52 Mbps on Iperf, and the media converter was identified as the possible problem. MRV's converter had certain settings that needed to be set on the small dials located on the side. After adjusting the settings, the data obtained showed continual improvement. However, the throughput was still not quite right. Since time was limited, MRV personnel conducted further testing in their labs after the testing event; and the results showed that the media converters were not set appropriately during the testing event.

The next FSO company, Lightpointe, connected their FlightStrata directly to the network routers. Their product used multi-mode fiber cable, and it operated at the wavelength of 850 nanometers. Since the GBIC ports on the routers were made for this exact type of fiber and wavelength, and an SC-type connection was used for the link head and GBIC, Lightpointe attained successful results of 80.3 Mbps on Iperf from the very beginning of the day.

Ensemble's 802.16 product attained lower data throughput readings than the other high throughput technologies such as FSO and Microwave. While Ensemble promoted their product at 66 Mbps of throughput, the actual capability when transmitting one way was 33 Mbps and the rest was reserved for traffic flowing the opposite direction. Data throughput averaged 10 Mbps, which was low comparatived to other companies. Most companies attained at least 50% of their link capability as measured by SolarWinds or Iperf. One reason for this slow speed was that Ensemble used a single-mode fiber cable to connect to the GBIC port on the router. Fortunately, the GBIC accepted the single-mode cable, even though the GBIC was designed for multi-mode fiber. Second, Ensemble's single-mode fiber was equipped with an ST connector. Thus, an ST to SC converter had to be used between the cable and GBIC port. On another topic, the ATM configuration on the network router for Ensemble's product proved to be inconvenient and time-consuming. There was no plug-and-play capability like the IP based technologies.

GDDS brought out their DSUs for this testing event. These devices normally allow users in the COC to access any radio or phone line that is located on the Antenna Hill. While the accessing of radios and phone lines was not attempted during this testing event, the ability to communicate VoIP through the DSUs was demonstrated. A DSU and GDDS's laptops with the appropriate GUI software were connected to the LAN switch on both sides of the network to enable this to happen. However, in order to accomplish this, both networks needed to be on the same subnet. This was a drastic change from the three separate subnets utilized throughout the testing. While this was beneficial to demonstrate, it showed the current limitations of the DSU. Serious consideration needs to be given to how this can be employed when COC to COC and/or COC to Antenna Hill communication is required.

As mentioned earlier, VoIP was utilized through the DSUs. It was also accomplished through the use of the Cisco IP phones in the network. SolarWinds read the throughput of a phone call at 90 Kbps no matter which technology was employed. Although this was not a significant amount of bandwidth utilized while employing high throughput technologies, it could prove to be a burden on the Marine Corps' current equipment such as the MRC-142. With the use of multiple phones at the same time, the entire bandwidth could be taken up by voice only.

The KG-235 INE crypto devices used during this event were intended to bulk encrypt all traffic over the wireless link being tested, except 802.11b with SecNet-11. This was done because the technologies did not have built-in encryption techniques. A trained KG-235 operator and the students determined that since the entire network was set up with three different subnets the KG-235 could not be placed between the link product and the network router. The 192.168.2.x subnet was established on the outside of each router and was the subnet of the wireless link between the two LANs. The two KG-235s needed to be on separate subnets to function properly together. Therefore, the router was eliminated in both networks and the KG-235 replaced it. The KG-235 at the MRF was set as the 192.168.3.x subnet and the other KG-235 was programmed for the 192.168.1.x subnet. Unfortunately, the fill on the KG-235 at the MRF kept dropping, so the configuration on the KG-235 kept dropping out. Thus, no connectivity could be accomplished.

Finally, even though the IMUX device used to combine four Iridium channels was not functional during the testing, the authors were able to gain some insight into how the capability could fit into the Marine Corps communications architecture. Since the four antennas sit on a metal stand and connect to the IMUX box via an RF cable, the IMUX did not seem to be a means of communication for on-the-move. It would have to be set up at a company-sized or larger COC. Special mounting options would have to be explored to mount the antennas on vehicles if there was a requirement to use it on-the-move. In addition, an Iridium phone must be attached to the IMUX device in order to use one of the channels. This is somewhat of an inconvenience, but there is an advantage because while using the phone others can use the three other channels. A compression algorithm such as the one Dr. Abousleman demonstrated to the students would need to be used with the Iridium service due to its low throughput capabilities.

2. Analysis

The SolarWinds and Iperf data varied considerably throughout the testing event. Iperf data always gave higher throughput readings due to the consistent size of packets being generated from computer to computer. Although the SolarWinds reading is a more accurate depiction of how traffic will flow in the tactical environment as various size files, e-mails, and phone calls will be made, Iperf proved beneficial because it offered a quick method to determine how much throughput could be achieved with an ideal load flooding the network from computer to computer. However, this scenario does not accurately depict the traffic flow in any network.

Another cause of the lower throughput data when measuring it from within the LAN compared to computers directly attached to the link is the ability of the routers and the switches. When data is sent from the computer within the LAN, the switch and router may experience traffic entering the device faster than it can send it. Thus, significant overhead starts to build on the device and traffic in the network is slowed down. When the computers are connected directly to the link, the overhead factor is eliminated because there are no switches and routers to slow the traffic. The only limiting factor is the computer capability to send and receive data.

When transferring data between two bridges, the SecNet-11 equipment required that one bridge be set at 'Master' and the other at 'Slave'. The bridge at the side of the

192.168.3.x network was set for ‘Master’ and the other bridge at the 192.168.1.x network side was set for ‘Slave’. The throughput when going from ‘Master’ bridge to ‘Slave’ bridge was twice as large as it was when going from ‘Slave’ to ‘Master’. The SecNet-11 bridges are designed for half-duplex transmission when communicating between the two. Therefore, when setting a bridge configuration to ‘Master’, there should be consideration for where that bridge is located, i.e., at a node where most of the traffic will be leaving. As for the packet loss in the bridge-to-bridge configuration, the parabolic antennas used required relatively accurate pointing due to their tight beamwidth of eight degrees. These antennas were most likely slightly off in their alignment, as the weather and distance were not a factor in causing the packet loss.

The data collected for the SecNet-11 access point showed that there were significant disadvantages of going to a completely wireless LAN. The ability of the access point to transfer data expeditiously drops off as more wireless computers are used on the access point. It may be beneficial to have the users requiring wireless connections do so, but the ones who can stay near the access point and networking equipment remain wired. In addition, the computer wired to the network does not require a SecNet-11 card because the traffic from the wireless computer to the access point is encrypted, but the access point decrypts the traffic prior to routing it over the CAT-5 cable from the access point to the switch.

Since the Cisco switch provided with the RFM product was set for auto-negotiation, and the network Cisco routers and switches were set for speed 100 Mbps and full duplex, serious degradation in the RFM link was apparent. The ports on the RFM Cisco switch need to be configured the same as the network ports. This allows for a more stable and reliable RFM link.

fSONA needed a different type of GBIC on the router to directly connect their single-mode fiber from the link head. Great lessons were learned about fiber connectors. First, the type of fiber connector was important since there are a multitude of connectors and many of them look similar. Next, the wavelength and type of mode that a port, such as a GBIC, supports was important to identify early on. These two important points can be easily overlooked, but will affect connectivity.

MRV's media converter problems showed the need of knowing the media converter and the proper settings. Each company came to the testing event with different converters, and none were set the same way. For some reason, the MRV media converter needed the dials on the side of the device to be set; and most of the other companies' media converters did not require this type of setting. The authors recommend using a media converter that is plug-and-play.

Lightpointe enjoyed the success of directly connecting their link head to the network router with fiber, and they also experienced the highest throughput results of all the FSO companies. By eliminating the need for the media converter, Lightpointe was able to avoid the change in cable that the other companies encountered by going from fiber to CAT-5. In order to address the issue of the different types of GBICs required, a solution was to have one available for all the different types of fiber and wavelengths on hand. The GBIC could be easily switched out on the Cisco router. The use of fiber anywhere in the network would significantly increase the throughput capabilities.

Ensemble would have been better served with a proper single-mode capable GBIC. While having the different types of interface converters on hand is convenient, a media cross connect device that connects all the types of connections and different wavelengths would be beneficial. MRV Communications makes this type of device, where any type of fiber connection can be added to the device to give a multitude of options for wavelength and connector capabilities. In addition, on the same device, copper and serial connections can be added. Far too often, the authors found themselves struggling with an array of connections that the different companies required. Furthermore, ATM type products required too many configurations on the routers and offered no benefit over IP based products. Therefore, the Marine Corps should adopt IP based technology. Ensemble did inform the authors that they were developing an IP based product. However, in April the board of directors for Ensemble decided to shut the company down.

The DSU testing was a success due to the ability to talk via VoIP from the laptop computers. Since the DSUs are normally employed for COC to Antenna Hill scenarios, the VoIP test showed that operators in the COC could talk to those at Antenna Hill as long as some type of network was set up there. For example, the mode of communication between COC and Antenna Hill was via a switch at Antenna Hill. Then, the DSU and computer connect to the switch to form the required network. This scenario could realistically have users on the same subnet. However, if communications were being established between two COCs, they most likely would be on different subnets. In conclusion, the DSUs need to be researched further to determine if they can be used when communicating between separate subnets. If they cannot, then the UOC units will be subject to a 'flat' network across multiple sites in order to employ VoIP through the DSU.

With the use of VoIP phones within a network, the Marine Corps in the future could eliminate the need to employ switch-based equipment, such as the A/N TTC-42 or SB-3865. This will only happen though if the Marine Corps adopts some of these higher throughput technologies to provide inter-nodal communications because of the amount of bandwidth required by VoIP. Another option is to employ Coder-Decoders (CODECs) that reduce the size of the packets being sent for VoIP phone calls.

Next, the KG-235 acts as a router but it cannot be programmed to run specific type of routing protocols. While the scenario for this testing allowed the authors to eliminate the network routers for the crypto devices, serious consideration needs to be given to the IP routing scheme for COC to COC connectivity and whether utilizing a routing protocol is important. The KG-235 would be sufficient for establishing encrypted traffic from the COC to Antenna Hill as the local unit easily controls the intra-nodal communications IP scheme.

Finally, if the IMUX device can be packaged in a more effective manner for small on the move units, such as platoons, then this device can prove significant. Battalion and higher COCs will benefit from this device very little if smaller sized units do not have the capability of the Iridium channels. The battalion or higher COCs do not need this device to talk with higher headquarters as they will have much higher throughput means to communicate.

C. FIELD TEST #3 (RAYTHEON)

1. Findings

The findings discovered during Raytheon testing are discussed chronologically. The chronological order will consist of the baseline test, Lightpointe, SecNet-11, Ensemble, Terabeam, In-line Network Encryptor (INE), Radio Frequency Module (RFM), MRV, MRV-RFM Switchover, fSONA, Voice over Internet Protocol, Alvarion, and Iridium Inverse Multiplexer (IMUX).

Lightpointe was the first company tested because they were a local company and were available to assist in the baseline testing. The baseline testing revealed it was going to be a challenge to communicate at a distance of 6.7 kilometers. The initial tests, data transfer test (SolarWinds) and Iperf, indicated about a 30 Mbps throughput across the network. It should be made clear that SolarWinds and Iperf are two diverse tests and their applications are dissimilar. SolarWinds was a program used to monitor throughput across the network. Iperf was a program that generated data across the network and displayed the results in a text file. In addition, SmartBits was used to generate data across the network and display the results in a spreadsheet. During the baseline testing, the SmartBits system changed the frame size while keeping the throughput constant. This SmartBits test indicated an overall average frame loss percentage of 4.37. The graphical representation of this test is represented in Figure 34 (SMARTBITS RAYTHEON BASELINE GRAPHICS). The other baseline product tested was SecNet-11. The two tests conducted while using SecNet-11 were SolarWinds and Iperf. SolarWinds indicated an average throughput of 1.64 Mbps while Iperf had an average of 1.3 Mbps.

On February 3, the findings for Lightpointe indicated a steady link with zero percent packet loss. The average throughput for Lightpointe while using SolarWinds was 27.5 Mbps, and the average throughput using Iperf was 35.8 Mbps. The disparity between SolarWinds and Iperf was due to the type of TCP flow control protocols that are inherent in the TCP/IP network. According to Douglas Comer, flow control is defined as "a protocol mechanism that allows a receiver to control the rate at which a sender transmits data. Flow control makes it possible for a receiver running on a low-speed computer to accept data from a high-speed computer without being overrun."[60]

SolarWinds demonstrated a stop-and-go flow control mechanism being used in the network. The stop-and-go technique is an inefficient technique to pass data across a network because it waits for an acknowledgement from the distant computer that the distant computer is ready to receive the transmitted data.[61] The throughput fluctuated when the type of data (Word, Power Point, Excel, or Adobe documents) changed or the size of the file changed during the transfer data test. It was clear to see that the stop-and-go technique was being used between the two computers in order to prevent data overrun across the network.

On the other hand, Iperf used what is called a sliding window technique for TCP flow control. According to Comer, "the sender and receiver are programmed to use a fixed window size, which is the maximum amount of data that can be sent before an acknowledgement arrives."[62] The sliding window technique was observed with data collected from the Iperf test. The type of data generated across the network by Iperf and by SmartBits was clean, steady, uniform data packets sent at a uniform rate; therefore making it easier to apply the sliding window technique. The SmartBits data on Lightpointe revealed a throughput above 30 Mbps resulted in a frame packet loss of 27.3 percent. During the SmartBits test, the frame size was kept constant and the size of the data being transmitted across the network was increased by increments of 10 Mbps. Executing the SmartBits test was extremely difficult at the beginning of the Raytheon test. The authors were inexperienced in operating the software and the hardware. This resulted in the test conducted during baseline testing being different from the test conducted on the first day of testing.

On February 3, unexpected low throughput was experienced over SecNet-11, which was not expected after having an impressive day of baseline testing. Antenna

---

[60] Douglas Comer, "Computer Networks and Internets with Internet Applications", (Prentice-Hall Inc, New Jersey 2001, third edition), pg. 611.

[61] Douglas Comer, "Computer Networks and Internets with Internet Applications", (Prentice-Hall Inc, New Jersey 2001, third edition), pg. 259

[62] Douglas Comer, "Computer Networks and Internets with Internet Applications", (Prentice-Hall Inc, New Jersey 2001, third edition), pg. 259

wind loading had a tremendous effect on the results. The majority of the day was spent stabilizing the antennas in order to conduct the test. The distant end secured equipment on their end with guy wire in order to prevent the antenna from swaying. On top of the Raytheon building, an individual held the antenna and pointed the antenna in the direction of the distant end while the test was being conducted. The results from SolarWinds indicated a 540 Kbps maximum throughput. The throughput also varied depending on the type of data being transmitted. The Iperf test resulted in two very dissimilar results. The first run had an average throughput of 156.9 Kbps while the second run had an average throughput of 450.2 Kbps. The diverse results indicate the level of trouble the testers had in attempting to overcome antenna wind loading.

The Ensemble test resulted in observing that an ATM network took time to configure and establish. The Iperf data averaged around the expected value of 28.9 Mbps. The throughput monitored by SolarWinds indicated an average value of 5.96 Mbps with zero packet loss. The outcome of the SmartBits data was to observe where the maximum throughput was located, to determine where SolarWinds was dropping the link, to measure the amount of packet loss when the throughput was doubled, and to examine the link with an over-saturation of data. The first run indicated a maximum throughput somewhere between 20 and 30 Mbps. The second run indicated that SolarWinds was showing the link down when the link was over-saturated with data. The problem was that the link was not down because VoIP was still operational over the link while the over-saturation was taking place. The saturation point was somewhere between 30 Mbps and 40 Mbps. The data table did not reveal the exact saturation point. However, it did show the packet loss. SolarWinds has an upper threshold that if the packet loss is over 30%, then the link is identified as being down (this was a newly found inherent property that was discovered during this test). The data in the table below shows the packet loss over 30% at 33 Mbps, which is where SolarWinds identified the link as being down (Table 41).

SECOND RUN	Load (%)	Throughput	Sent	Received	Lost	Loss (%)
Total	30	30	48756	37589	11167	22.9039
Data Group	N/A	30	47800	36860	10940	22.887
TEST Group	N/A	30	956	729	227	23.7448
Total	31	31	50388	37593	12795	25.393
Data Group	N/A	31	49400	36856	12544	25.3927
TEST Group	N/A	31	988	737	251	25.4049
Total	32	32	51918	37524	14394	27.7245
Data Group	N/A	32	50900	36788	14112	27.725
TEST Group	N/A	32	1018	736	282	27.7014
Total	33	33	53550	37534	16016	29.9085
Data Group	N/A	33	52500	36803	15697	29.8991
TEST Group	N/A	33	1050	731	319	30.381
Total	34	34	55182	37538	17644	31.9742
Data Group	N/A	34	54100	36794	17306	31.9889
TEST Group	N/A	34	1082	744	338	31.2385
Total	35	35	56814	37405	19409	34.1624
Data Group	N/A	35	55700	36668	19032	34.1688
TEST Group	N/A	35	1114	737	377	33.842
Total	36	36	58446	37552	20894	35.7492
Data Group	N/A	36	57300	36806	20494	35.7661
TEST Group	N/A	36	1146	746	400	34.904
Total	37	37	60078	37559	22519	37.4829
Data Group	N/A	37	58900	36831	22069	37.4686
TEST Group	N/A	37	1178	728	450	38.2003
Total	38	38	61710	37560	24150	39.1347
Data Group	N/A	38	60500	36832	23668	39.1207
TEST Group	N/A	38	1210	728	482	39.8347
Total	39	39	63342	37567	25775	40.6918
Data Group	N/A	39	62100	36850	25250	40.6602
TEST Group	N/A	39	1242	717	525	42.2705
Total	40	40	64974	37569	27405	42.1784
Data Group	N/A	40	63700	36865	26835	42.1272
TEST Group	N/A	40	1274	704	570	44.741
FrameSize	1518					
Throughput (% max load)	40					
Frame Loss (%)	42.17841					

Table 41. ENSEMBLE'S CONFLICTING DATA

The third run was conducted to measure the amount of packet loss when the throughput was doubled. The run revealed that when the throughput was doubled, the packet loss increased. The data obtained from the SmartBits fourth run was an exaggeration of the third run. The goal for the fourth run was to see the link get over-saturated with data. The data table below demonstrates the link getting over-saturated (Table 42).

FOURTH RUN	Load (%)	Throughput	Sent	Received	Lost	Loss (%)
Total	10	10	16218	16218	0	0
Data Group	N/A	10	15900	15900	0	0
TEST Group	N/A	10	318	318	0	0
Total	20	20	32436	32436	0	0
Data Group	N/A	20	31800	31800	0	0
TEST Group	N/A	20	636	636	0	0
Total	30	30	48756	37590	11166	22.9018
Data Group	N/A	30	47800	36860	10940	22.88703
TEST Group	N/A	30	956	730	226	23.64017
Total	40	40	64974	37568	27406	42.17995
Data Group	N/A	40	63700	36850	26850	42.15071
TEST Group	N/A	40	1274	718	556	43.64207
Total	50	50	81192	37545	43647	53.75776
Data Group	N/A	50	79600	36758	42842	53.82161
TEST Group	N/A	50	1592	787	805	50.56533
Total	60	60	97512	21164	76348	78.296
Data Group	N/A	60	95600	20757	74843	78.28766
TEST Group	N/A	60	1912	407	1505	78.71339
Total	70	70	113730	21161	92569	81.39365
Data Group	N/A	70	111500	20741	90759	81.39821
TEST Group	N/A	70	2230	420	1810	81.16592
Total	80	80	129948	21790	108158	83.23175
Data Group	N/A	80	127400	21369	106031	83.22684
TEST Group	N/A	80	2548	421	2127	83.47724
Total	90	90	146268	21799	124469	85.09654
Data Group	N/A	90	143400	21367	122033	85.09972
Total	100	100	162486	1452	161034	99.10638
Data Group	N/A	100	159300	1422	157878	99.10734
TEST Group	N/A	100	3186	30	3156	99.05838
FrameSize	1518					
Throughput (% max load	100					
Frame Loss (%)	99.10638					

Table 42. ENSEMBLE OVER-SATURATED

The testing for Terabeam included information about the optical scope, the auto tracking feature, and the easy setup. The optical scope was used to align the two lasers. The alignment process took a total of five minutes. The auto-tracking feature compensates for the swaying of buildings or the movement of the distant laser. The setup of the Elliptica was done quickly and efficiently. The findings provided the following insight when using the Iperf test: if the window size was too low, then the data throughput would result in a lower value. For instance, the two Iperf runs below demonstrate different throughput results by varying the window size of the send and receive buffers of the computers. The data below is a window size of 63 Kbytes:

```
------------------------------------------------------------
Client connecting to 192.168.1.2, TCP port 5001
TCP window size: 63.0 KByte (default)
------------------------------------------------------------
[928] local 192.168.3.3 port 1068 connected with 192.168.1.2 port 5001
[ ID] Interval        Transfer      Bandwidth
[928]  0.0- 5.0 sec   34.0 MBytes   54.3 Mbits/sec
[928]  5.0-10.0 sec   26.2 MBytes   42.0 Mbits/sec
[928] 10.0-15.0 sec   27.3 MBytes   43.6 Mbits/sec
[928] 15.0-20.0 sec   28.0 MBytes   44.8 Mbits/sec
[928]  0.0-20.0 sec    116 Mbytes   46.2 Mbits/sec
```

Now when the data above was compared to a window size set at 0.1 Mbytes, the result was a bigger throughput for the Iperf test (see below for results).

```
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size:  0.1 MByte
------------------------------------------------------------
[920] local 192.168.3.3 port 5001 connected with 192.168.1.2 port 1059
[ ID] Interval        Transfer      Bandwidth
[920]  0.0- 1.0 sec   8.7 MBytes    69.7 Mbits/sec
[920]  1.0- 2.0 sec   9.8 MBytes    78.4 Mbits/sec
[920]  2.0- 3.0 sec   9.7 MBytes    77.4 Mbits/sec
[920]  3.0- 4.0 sec   10.7 MBytes   85.3 Mbits/sec
[920]  4.0- 5.0 sec   10.2 MBytes   81.3 Mbits/sec
[920]  5.0- 6.0 sec    9.5 MBytes   76.3 Mbits/sec
[920]  6.0- 7.0 sec    10.9 MBytes  88.3 Mbits/sec
[920]  7.0- 8.0 sec    10.9 MBytes  87.2 Mbits/sec
[920]  8.0- 9.0 sec    11.3 MBytes  90.2 Mbits/sec
[920]  9.0-10.0 sec    10.9 MBytes  87.0 Mbits/sec

[920]  0.0-10.0 sec    10.3 MBytes  82.1 Mbits/sec
```

As can be seen, adjusting the window size of the data being transferred was very important when conducting the Iperf test. Equally important were the results of SolarWinds. This test indicated that VoIP and video programs could run in the background while data was transferred from one network to another. The average throughput while these tests were conducted was 16.5 Mbps and the packet loss observed was zero. Two runs using SmartBits were conducted. The first run measured the data transfer between the two local area networks while the second run measured the data and VoIP transfer across the network. Both SmartBits tests were measured to a total throughput of 100 Mbps with an incremental increase of 10 Mbps. The frame loss for the data portion was 0.33 percent, while the frame loss for the data and VoIP portion was 0.37 percent.

The findings for the KG-235 Sectéra In-Line Network Encryptors (INE) were that the INE needed the latest firmware for higher throughput capabilities and the authors were expecting a higher throughput result from the product. When the INE was tested at Raytheon, the INE had an older version of firmware installed. The INE manufacturer specifications rate the product up to 17 Mbps aggregate data throughput.[63] However, upgrades are being done in order to increase throughput to 60 Mbps. The maximum throughput observed for the INE during testing was around 5 Mbps. The average Iperf throughput for the two runs while connected to the Terabeam link was 3.6 Mbps. Later in the week, the INE was connected to the fSONA link and the maximum Iperf throughput was 4.98 Mbps. While connected to the Alvarion link, a BLOS product, the average Iperf throughput was 2.4 Mbps. When the INE was connected to the IMUX, an OTH product, the average Iperf throughput was 7.7 Kbps. Thus, the throughput varied depending on the product providing the link for the network.

The Radio Frequency Module (RFM) product comes packaged in a hardened case to withstand a rugged military environment. The product performed as expected as a series of tests were conducted using an Iperf test, a data transfer test monitored by SolarWinds, and a SmartBits test. The average maximum Iperf throughput was 88.2 Mbps, and the average maximum SolarWinds throughput was 40 Mbps. The SmartBits

[63] http://www.gdc4s.com/Products/secteraspecs.htm

test generated 20 VoIP phone conversations going across the network along with 100 computers passing information simultaneously across the network. The test showed less than 0.23 percent packet loss across the network as the load on the network was increased in 10 Mbps increments up to 100 Mbps.

The findings for MRV were as expected. Even though the windy conditions presented a problem on top of the Raytheon building, the average maximum Iperf throughput resulted in 89.7 Mbps, and the maximum throughput recorded while using SolarWinds was 59 Mbps. During the SolarWinds test, there were runs where only data was being transferred, there were runs where VoIP was running in the background as data was being transferred, and there were runs where VoIP and video clips were being played as the data was being transferred. The SmartBits test consisted of 100 simulated computers sending data across the network along with 20 simulated phone conversations across the network. The test increased the throughput in 10 Mbps increments until the link reached 100 Mbps. SmartBits revealed a solid link with no packet loss for the test.

The finding from the MRV-RFM Switchover, MRV's OptiSwitch, was a seamless switchover between the RFM and MRV's Terescope. In order to capture the hand-off from one product to another, two tests were run simultaneously. The SmartBits test generated the data across the network while the SolarWinds test collected the nodal throughputs of the data being transmitted. The results recorded were a 54 Mbps throughput when the data was going across the FSO link and a 33 Mbps throughput when the data was going across the RFM link. The hand-off was a seamless transition, as the user did not notice a break in the link. SmartBits revealed a fifty percent packet loss, which was expected because the FSO link had to be broken in order for the RFM to pick up the link.

The findings for fSONA were as expected. The maximum average Iperf throughput was 89.13 Mbps. The results from SolarWinds showed a maximum throughput value of 53 Mbps. During the SmartBits test, fSONA demonstrated the lowest frame loss percentage when compared to the other FSO companies. For the SmartBits test, 100 computers were simulated passing data across the network and 24 phone conversations were simulated passing information across the network. From the

SmartBits results, fSONA demonstrated a frame loss percentage of 0.0018 percent. This low frame loss percentage may be a result of fSONA's laser being able to produce a power output of 640mW, a considerable difference over all other companies. fSONA's demonstration of a reliable link and of a product that can be integrated as a technical solution for the next generation of wireless technologies highlights the endless capabilities of wireless technologies.

The findings for VoIP demonstrated that quality of service depended on how solid the link was between the sites, and VoIP remained operational across a degraded link. Quality of service was directly proportional to the quality of the link. If the quality of the link was above average, then the quality of service for VoIP was the same. VoIP had a unique quality that was interesting. Due to the priority settings in the network routers, voice was set for the highest priority, so VoIP was able to operate although the network was indicating a degraded status. When the quality of service was degraded, however, the phone call was still operational.

The findings for Alvarion were as expected for this BLOS product. The product has the capability of operating in speeds of 6, 24, or 54 Mbps. The product was tested with its integrated antenna and with a larger external antenna. The distance of the testing was 6.7 kilometers through a metropolitan area over to a ridgeline. The Iperf throughput finding for the integrated antenna was 3.0 Mbps. The Iperf throughput finding for the external antenna was 4.2 Mbps, and the SolarWinds test indicated the throughput was 4.92 Mbps. The SmartBits test revealed a throughput between 10-15 Mbps, with anything over 15 Mbps resulting in packet frame loss over 22 percent. When tested with the bulk encryption, KG-235, the Iperf throughput was 2.4 Mbps. It is important to point out that in order for the authors to have achieved a LOS link between the Raytheon building and the ridgeline on the Miramar base, the authors were required to place the product being tested on top of Raytheon's building. Alvarion's product was placed in Raytheon's parking lot, which was not LOS to the distant ridgeline.

The findings for the Iridium Inverse Multiplexer (IMUX) resulted in an average Iperf throughput of 7.7 Kbps. The IMUX has four satellite channels that are capable of passing 2.4 Kbps on each channel, resulting in a maximum throughput of 9.6 Kbps. The nice feature of the IMUX was that the sender could place a phone call while simultaneously transmitting an image across the link. The compression algorithm observed in the Mobile Research Facility allowed several Mbyte picture to be compressed and sent over the Iridium link within seconds. In addition, the sender could circle items of interest on the image that would not get compressed in order to enhance specific details of the images.

The following paragraphs will discuss the Analysis portion of each product chronologically.

2. Analysis

The analysis of the baseline test indicated lower throughput levels than expected for the FSO product. Expected values of the FSO product were to be in the range of 80 Mbps. The reason for the lower levels might have been due to a FSO product being introduced at a very long distance. Another reason could be that the baseline testing was conducted in rainy conditions. The rain might have caused less than perfect conditions for the beam of light to traverse across to the distant site. On the other hand, the throughput levels for the 802.11b product were higher than expected. The reason for the higher levels might have been due to more accurate pointing of the parabolic antennas.

The analysis of Lightpointe testing resulted in throughput values lower than expected. The authors can only speculate as to the reason why the maximum throughput was 35.8 Mbps. The reason may have been the distance between sites, weather conditions that day, alignment of the lasers, interface between the laser and the test bed, or configuration of the test bed.

The author's analysis of SecNet-11 testing resulted in a better understanding of antenna wind loading. With a maximum throughput of 540 Kbps, it was obvious that a directional antenna could deliver a bandwidth that could be beneficial in a tactical environment even in adverse weather conditions. In addition, SecNet-11 is a secure National Security Agency (NSA) Type 1 and FIPS-140 compliant encryption device.

The analysis for Ensemble indicated that an ATM network took time to configure and establish. In addition, the ATM network handled the transfer of voice, data, and video extremely well until the link became over-saturated. Ensemble's 802.16 product provided a reliable link with limited bandwidth when compared to FSO. The product performed as expected with Iperf, while SmartBits had greater throughput results than SolarWinds. The reason for the lower throughput in SolarWinds was that flow control was being handled twice, once through the ATM protocols and again through flow control measures in the computers sending and receiving the data.

The analysis for Terabeam resulted in throughput values that were expected from an FSO product. The most impressive observations were the optical scope, the auto tracking, and the easy setup. The data collected was a strong indicator that an FSO product could be used to connect different sub-systems for CAC2S. As long as the sub-systems were within line-of-sight, an FSO product like Terabeam's Elliptica could be used to pass data from one site to another.

The analysis for the KG-235 Sectéra In-Line Network Encryptors (INE) indicate that the product has a tremendous potential for encrypting commercial off-the-shelf wireless products. The maximum throughput for the INE was around 5 Mbps. In order to produce a higher throughput from the product, the authors discovered that the latest version of firmware needed to be installed on the INE. The throughput from each product was different. The FSO products were able to produce a higher throughput whereas the OTH product produced the lowest throughput. Along with the KG-235, other encryption devices provide bulk encryption for optical networks. The KG-189 could be used for increased throughput levels. According to SPAWAR, "the KG-189 program currently consists of models supporting three standard Synchronous Optical Network (SONET) data rates: OC-3 model operates at 155 Mbps, OC-12 model operates at 622 Mbps, and the OC-48 model operates at 2.5 Gbps."[64] However, the author's analysis revealed that the throughput was directly correlated to the bandwidth of the product being tested. In addition, each INE was assigned a different subnet in order for the two networks to communicate with each other. In order to pass information from one network to another, the laptops had to be configured on the same subnet as the INE.

64 https://infosec.navy.mil/ps/?t=infosecprodsservices/infosecprodsservices.tag&bc=/infosecprodsservices/bc_kg189.html

The analysis for the Radio Frequency Module (RFM) resulted in throughput values as expected from the product. The field engineers were able to configure the switch (provided with the RFM), to speed 100 and full duplex. This product would be a great fit for the sub-system connectivity in CAC2S.

The analysis for MRV resulted in values that were expected from a FSO product. MRV's Terescope performed extremely well in windy conditions. The stability on top of Raytheon's building initially presented a problem, which was solved by securing the laser optical stands. MRV's impressive reliability indicated that an FSO product could be utilized in an intra-nodal CAC2S environment.

The analysis for MRV's OptiSwitch resulted in much higher than expected performance. The seamless transition indicated that a component such as the MRV's OptiSwitch can be a vital element in an architecture that requires multiple technologies to operate simultaneously. In addition, a similar technology that has both RF and FSO embedded, such as MRV's Terescope Fusion, could potentially be the solution for an amalgamation of different technologies.

The analysis for fSONA resulted in data throughput levels that were expected. The power output for fSONA was higher than the other products tested which might have contributed to a lower frame loss percentage produced by fSONA. fSONA demonstrated that the LOS link was capable of passing a maximum throughput in the high 80's with outstanding reliability.

The analysis for VoIP indicated that the quality of service is not necessarily dependent on the quality of the link. This is to say that once the link has reached its maximum throughput level, the quality of the phone call degraded to the point of dropping the call. Once the call was dropped, the link was no longer operational. During one of the testing runs, the link became degraded but the phone call remained operational. The phone call remained intact because of the priorities that were established in the network's routers and because the phone call was placed over an IP based network, VoIP link.

The analysis for Alvarion indicated this type of product, a BLOS product, could be used in a metropolitan area for connectivity. Alvarion's Orthogonal Frequency

Division Multiplexing (OFDM) product showed a throughput that was capable of passing through power lines, buildings, and trees over a distance of 6.7 kilometers. Different types of antennas exist for this product. The scenario the equipment needed to address would determine the type of equipment used for an application. In addition, this product was tested in the Camp Roberts experiment in March. The product's testing in March demonstrated additional range characteristics and it also demonstrated communications on-the-move.

The following paragraphs discuss the Findings and Analysis of Field Test #4, Camp Roberts experiment.

D. FIELD TEST #4 (CAMP ROBERTS)

The following findings and analysis are provided to help further understand the results of the testing event conducted at Camp Roberts. The following topics are covered in the respective order: Mobile Access Router (MAR), Cisco 2950 switch between routers, Cisco 3550 switch, network module on Cisco 3745 router, Lightpointe, Terabeam, fSONA, Linksys 802.11a access points, VoIP, OFDM, tethered balloon, UAV, Segovia/Omega Systems, INMARSAT, Communications on-the-move, and IP based network.

1. Findings

The students intended to use the MAR as the key piece of equipment at the NOC, POP, MRC #1, and MRC #2. This router is the size of one's hand and would have allowed the students to integrate multiple technologies at one location and still effectively route traffic throughout the network. While the cards of this router are made by Cisco, a company called Western DataCom integrated the cards. The main problem encountered with the MAR was the configuration settings, which enable each router to communicate with one another. Despite the inability to employ the router during the testing event, LT Manny Cordero continued to pursue getting the router to function properly. During an NPS driven experiment in May at Camp Roberts, CA, the MAR showed its usefulness as Western DataCom representatives and LT Cordero finally put the configurations together. The setup in May was very similar to the student's testing in March. The MAR worked much like a Cisco Call Manager where all the phones communicated back to the server. For the MAR, a Home Agent was placed within the network and the rest of the MARs throughout the network talked back to the Home Agent. In May, the students were also able to see the MAR automatically switch between two technologies when one was degraded. These technologies were employed at the same time in a point-to-point scenario. Furthermore, the connections to the MAR that performed Layer 3 functionality were RJ-45 and smart serial.

On 8 March, the students inserted a Cisco 2950 switch between the two routers at the POP site. They did this in order to connect the OFDM and FSO links as well as to provide a LAN at the POP. While this setup worked, it was not the most desirable configuration. However, it was the only option for the equipment the students had on-hand. A computer connected to the switch in the LAN was configured for a gateway of 192.168.3.1 to communicate with MRC #1. To talk with the NOC, the gateway was set at 192.168.3.2. Therefore, separate computers at the POP were used to talk throughout the network, or one computer switched its gateway depending on the intended direction of communication.

In order to expand on the results acquired on 8 March, the students were able to attain a Cisco 3550 switch on 9 March, which was a Layer 2/3 capable device. This enabled the students to have one device handle the functions that took two routers and one switch the day prior. Specific ports on the 3550 switch were configured for the appropriate IP address of each subnet. However, the students were not able to enter an IP routing protocol into the Cisco Internetwork Operating System (IOS) for the switch. All of the other routers were using EIGRP. This meant that every device in the network that had routing capabilities needed to be manually told where to route. EIGRP would have automatically routed the traffic to the appropriate place as it learned what devices were around it. The manual routing statements in the Cisco IOS worked properly, but the students encountered problems getting to the MRC #1 site on that particular day. One of the problems could have been the routing statement in the Cisco 3550 switch to get to the MRC #1 site. Another problem could have been from Segovia's satellite link. They needed to tell their headquarters every IP address of the routers and 3550 switch in the network, and how each of these devices were expected to route. A mistake could have been made when configuring the satellite settings.

On 10 March, the students experimented with putting a 16-port Ethernet switch network module on the back of the 3745 router, which was located at MRC #1. The intent was to determine if the ports on the module were layer 3 capable. If so, this would have assisted the students in having one device with enough ports that could handle 802.11b and OFDM links as well as a LAN. Unfortunately, the ports could not be configured for Layer 3.

On 11 March, MRC #1 was in a similar situation as the POP site on 8 March. Two routers needed to be connected together through a switch in order to have two technologies at the site (802.11b and OFDM) and a LAN off the switch. This successfully worked as the computer connected to the switch at MRC #1 had a default gateway of 192.168.7.2 in order to communicate with the POP and NOC. To talk with MRC #2 the computer was set for a default gateway of 192.168.7.1.

Next, Lightpointe and Terabeam provided the two FSO links (March 8-9). While no data was sent over the FSO link, data was obtained from the NOC to MRC #1 via the POP site. Throughput readings on Iperf showed throughput of 4-5 Mbps on average. The best throughput reading on Iperf between the NOC and POP using OFDM was 12 Mbps. This data was then routed through the POP switch and through the FSO link head to another network. Based on testing experience, each network setup drops the throughput capabilities of a link by 10 –20%, which was most likely the cause of the drop from 12 Mbps to 4-5 Mbps.

fSONA's product did not establish connectivity during this testing event due to problems with the media converters. Reviewing the issue a week after the testing, it was realized that the media converters that fSONA used at Camp Roberts were the MC102XL's, which are multi-mode compatible. These units were NPS-owned and provided to fSONA for their use. At the time, the students did not know there were two types of media converters (single and multi-mode capable). The ones that fSONA used in past field-testing events with the SONAbeam-155M were MC103XL's, which are single-mode compatible devices. The mix up of media converters was the cause for the FSO link being down.

The students originally intended to use the Linksys WAP55AG 802.11a access points in bridge mode to conduct point-to-point communications. However, after attempting to configure them, the students determined that this could not be accomplished. The Linksys WAP11 access points, similar to the WAP55AG, that were used on the balloon and UAV could be configured for bridge mode. Therefore, the students did not expect to run into this finding. Since the WAP55AGs could not go into bridge mode, the students employed them in the LANs to allow laptops to connect wirelessly.

While using the VoIP telephones, 7960G and 7940G, the students determined that a specific protocol needed to be used by all the phones within the network as well as the Call Manager server. The Cisco Call Manager Skinny Client Control Protocol (SCCP) was employed for this purpose. An example of the differing protocols happened with the 7960G phones that were on temporary loan from Cisco. The two phones that arrived at NPS were each loaded with a different protocol, SGCP and SIP, and they could not communicate with each other. Furthermore, VoIP calls were made over the Segovia/Omega Systems satellite link, through multiple technologies, and through the tethered balloon. The calls over the tethered balloon proved troublesome since the link was unstable. The reason that a stable link is needed is that the phones throughout the network need continuous contact with the Call Manager server.

The OFDM technology proved most impressive during this testing event. Whether Alvarion or Redline was using their equipment to communicate over hills, through trees, or on the move, the technology definitely proved reliable. Since the signal being used was broken up into multiple carriers rather than a single carrier, the chances of getting connectivity increased tremendously. The OFDM technology equipment used by Alvarion and Redline is Layer 2 capable, thus an IP address is assigned to either the indoor unit for Alvarion or the AN-50 box for Redline. Furthermore, the distance capability of OFDM is out to about 20 kilometers depending on the antenna used. The students had seen it work out to 10 kilometers in a separate testing event.

The tethered balloon was one of the platforms available during this event to provide retransmitted communications. While working with the balloon, the students developed many concerns in employing this platform in a military environment. First, the reliability of getting the balloon airborne is of question. The balloon could not fly in bad weather such as high winds and heavy rain. When it was flying in winds above 10 knots, the balloon moved enough to cause significant packet loss of greater than 20% with a directional antenna employed on the ground. This leads the authors to recommend a ground-tracking antenna be employed on land to maintain connectivity with the balloon. Omni-directional antennas could be an option, but the gain on the antenna has to be enough to reach the distance. The packet loss encountered during the testing was enough to cause the network to be down for a significant amount of time. Finally, the balloon caused air traffic control issues. The UAV had to be deconflicted with it by distance and time. If for some reason the location of a tethered balloon did not get passed to the air control agencies and pilots, there could be serious problems with helicopters and UAVs flying through the tethered line.

While the UAV did not meet its mission as an airborne communications relay for this testing event, a great deal of learning occurred with airborne and ground antennas. First, the placement of the antenna on the UAV needs to be tested extensively in order to obtain the best radiation pattern results. In addition, omni-directional antennas need certain sized base plates in order to maximize the radiation patterns. On the wooden platform that was attached to the UAV, the antenna was located on the side of the board and it was placed through the platform. This did not allow for signals to radiate out of the antenna in an optimal manner. Regardless of the orientation of the antenna, it needed to have a base plate of the appropriate size for the antenna. Furthermore, the antennas on the ground need to be either omni-directional or tracking. The omni-directional antenna needs to have enough gain or amplification to reach the UAV. A tracking antenna will be optimal as long as GPS coordinates could be constantly fed to the antenna from the UAV. This type of antenna allows for a more directional beam to be sent to the UAV antenna.

The Segovia/Omega Systems team was able to configure their satellite system to provide a satellite link within a private network established by the students. Segovia did this by communicating to their headquarters the network scheme and how traffic needed to be routed. Therefore, the students were able to use the airborne satellite as a relay station between the NOC and POP. This did not seem to be a normal mission performed by Segovia, since they normally provide phone and Internet services. However, the Segovia/Omega Systems team showed their diversity in the type of services they could provide to their customer. The throughput they provided was 256 Kbps on 9 March and up to 1 Mbps on March 10-11. Furthermore, after being exposed to their mounted satellite system on the truck, Segovia/Omega Systems proved to be a solid possible solution for the CoNDOR POP vehicle satellite system.

During the testing, the students were able to see how well Nera's INMARSAT link performed on-board a moving vehicle. The satellite antenna was very easy to mount and keep stable while employed on the vehicle. Since Nera's modem was unable to interface with the private network established by the students, they could not incorporate their satellite link into the network. However, Nera did state they could do this with the right assets. On the other hand, Nera was able to show the capabilities of their Internet and phone services while on the move. The throughput was only 64 Kbps, but Nera did state they are developing a 256 Kbps link.

Communications on-the-move proved to be challenging for numerous reasons. For example, mounting the equipment onto the different vehicles created some difficult scenarios for the research team. Wooden platforms were used to mount tripod stands, which incorporated OFDM antennas and omni-directional antennas for the tethered balloon and UAV. The Nera satellite terminal was also mounted on a wooden platform. Some innovative HMMWV mounting options have already been addressed in the Marine Corps Signals Intelligence community. The HMMWV has a radar device mounted on top of the vehicle (just above the area where the driver and passenger sit). A satellite system could be mounted in the same area. In addition, this vehicle has an antenna mount that attaches to the frame of the vehicle just next to the passenger door. Implementing concepts such as these can make communicating on the move more feasible for military personnel.

This testing event demonstrated the advantage of an IP based network. This type of network allows any IP based technology to plug-and-play anywhere within the network. In addition, several technology methods were evaluated in this testing event in order to communicate BLOS and OTH to include OFDM, the tethered balloon, the UAV, and Broadband satellite.

2. Analysis

The MAR could effectively be employed with any of the programs studied in this research: UOC, CAC2S, and CONDOR. For UOC and CAC2S, the MAR could be employed as a means to route traffic in an intra-nodal situation where two wireless technologies are used in a redundant manner between COC and Antenna Hill for the UOC and between PDS, SDS, and CS sites for CAC2S. The MAR could also be utilized for inter-nodal communications for UOC and CAC2S nodes that displace quite often. The units that stay stationary probably should use regular network routers, such as the Cisco 3745 used in this testing experiment. Furthermore, the MAR would be especially useful at the CoNDOR POP vehicle. This site will be managing multiple nodes and multiple technologies. The only dilemma for the MAR could be the types of connections from the multiple radios the Marine Corps uses.

Despite the unfavorable setup of a switch between the two routers at the POP, the results yielded from the 8 March experiment show the diversity of a network configuration. IP traffic can flow in a variety of ways as long as one has the imagination to make it happen. On the other hand, an easy solution to this situation would be to have a router that possesses a sufficient amount of Ethernet ports for the scenario. For the POP, the router would have needed three ports: one for the FSO link, one for OFDM, and one for the LAN.

The author's concluded that the Cisco 3550 switch was not the appropriate device for the POP site in order to handle multiple connections. Even though the switch is Layer 3 capable, it did not perform like a regular Cisco router. A solution to the problem could be to use the Cisco 3745 router with its two Fast Ethernet ports that come with the router. In addition, a 2FE-2W-V2 network module could be inserted into the back of the router to give an extra two Fast Ethernet ports. If more ports are needed, the router is capable of receiving multiple network modules to provide the amount of ports desired.

The 16-port Ethernet switch network module used on the router at MRC #1 was Layer 2 capable only. Thus, an IP address could not be assigned to the port. While it is convenient to have a router and a switch on one device, the cost of the module is more expensive than a regular Cisco 2950 24-port switch.

Again, the Cisco switch between the routers at MRC #1 on 11 March was a solution based on availability of equipment. The easiest solution would have been to insert a two-port Fast Ethernet module (2FE-2W-V2) into the Cisco 3745 router to give the router four Fast Ethernet ports.

When Lightpointe and Terabeam were set up at MRC #1, they were providing a link between that site and the POP. The test results demonstrated that the slowest link in the network dictated the data throughput of the other links. Since OFDM was limited to 12 Mbps between the NOC and POP, the FSO link between the POP and MRC #1 did not speed up the data transfer when communicating from the NOC to MRC #1. The data was transferred at the rate of the OFDM link, since the two links were connected in series.

The mix-up with the fSONA media converters made it evident to the research team that having the correct media converter available could determine whether a positive or negative outcome could be achieved in a testing experiment. The two types of media converters mentioned in the analysis section above looked exactly the same, so the difference between the two was not evident. This was one more reason why running fiber cable between the FSO link head and the network router is more beneficial. The other reason is that throughput can be increased.

The WAP55AGs are Linksys products, a lower end variant of Cisco equipment. Neither Cisco or Linksys access points can do NSA certified Type-1 encryption, but they can do AES or Triple DES encryption. A determination needs to be made whether DoD is willing to accept AES or Triple DES encryption within a wireless LAN. If so, then the Cisco or Linksys products are viable options within the LAN.

Cisco IP phones can change protocol loads, but one phone cannot have more than one protocol loaded onto it at any given time. The most appropriate protocol for the scenario needs to be accomplished prior to starting an operation. The VoIP phones performed poorly with the 25-50% packet loss that was being experienced through the tethered balloon when it was relaying 802.11b signals. If VoIP calls were made the routing priority on the network routers, the chance of maintaining the call was much greater.

OFDM technology is a good fit for UOC and CAC2S in an intra-nodal scenario. This technology allows antennas and other communications equipment to be put in valleys where the gear can be camouflaged more effectively. In addition, wires do not need to be run over long distances. OFDM is also effective over long distances for inter-nodal communications. Even if two nodes are located outside the range of a point-to-point link, OFDM can be retransmitted to increase the distance. The difference in retransmitting is that there is increased flexibility of the placement of the antenna, and there is no longer the need to put it on top of a hill. This technology can also be used in a Military Operations in Urban Terrain (MOUT) environment since it works around buildings. Furthermore, OFDM can be used while on the move. This allows for connectivity within a convoy of vehicles that need to exchange video, voice, and data. If a UAV is flying overhead providing information to one of the vehicles in the convoy, then that vehicle can easily pass the information to the others via OFDM. The convoy can also maintain whatever security posture deemed necessary because OFDM communications does not limit the spacing of the vehicles.

The tethered balloon cannot be relied on to provide tactical communications. It presents security issues by giving away friendly positions, and it is too dependent on weather conditions. In addition, the logistics of getting helium bottles and a heavy launch platform around the battlefield are key concerns in adapting this platform for tactical communications.

The UAV is a more realistic method of relaying communications on the battlefield. The platform used from MLB Company was quiet and very hard to detect while airborne. As long as these platforms can remain stealthy, they can provide a powerful tool for communicators in the Marine Corps. With the Pioneer being the only Marine Corps UAV, there will be major problems when tasking this aircraft for communications missions rather than reconnaissance. However, the platform can perform a dual role when applicable since an airborne communications payload could remain relatively lightweight. If the Pioneer was not an option, the Marine Corps could look at future generation UAVs to be outfitted with a communications relay package on board. Additionally, the Marine Corps could look at outfitting other aircraft such as the C-130 with an airborne relay package. The C-130 that flies the Direct Air Support Center missions can loiter over the battlefield for 12 hours at a time.

For the Segovia/Omega Systems team, a challenge will be how much the services will cost the Marine Corps. The advantage that Segovia/Omega Systems possesses is that they have proven that they can work their satellite system into a private Marine Corps battlefield communications architecture, and they can provide the required Internet connectivity for the NIPRNET and SIPRNET. If VoIP is implemented into the communications architecture, then the Marine Corps can provide phone services internally and they do not need to rely on Segovia for this service. Finally, Segovia/Omega Systems can be utilized in the UOC, CAC2S, and CoNDOR communications architecture. They have a small footprint, minimal power requirement, and a powerful ability to provide broadband satellite connectivity.

With the Marine Corps command centers struggling to maintain connectivity while on the move, Nera's INMARSAT satellite link offers a possible viable solution. When UOC or CAC2S units send forward elements out, the forward echelon can keep their common operational picture up-to-date which allows for an easier and quicker displacement. One disadvantage to the INMARSAT services is that it is very expensive. Thus, further cost-benefit analysis is needed.

To communicate on the move, vehicles need to be outfitted with the proper mounts to place the antennas. OFDM antennas can be reduced in size to provide connectivity while on the move. For example, in May Redline offered to try six-inch antennas with their equipment for a demonstration to Special Operations Command. Furthermore, MRC vehicles already have antenna locations on the back of the vehicle that can be used while on the move. Thus, these vehicles could be outfitted with the appropriate antenna to maintain connectivity with an airborne relay platform.

Overall, this testing evolution was conducted to show how a CoNDOR architecture could look with currently available commercial technologies. This research event also directly applied to the UOC and CAC2S programs as they continue to look for innovative methods to communicate between and within nodes.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. CONCLUSIONS

The Marine Corps is developing new command and control systems such as UOC and CAC2S, and new concepts for Marine Expeditionary Forces to bridge the gap between Major Subordinate Commands (MSC) and their subordinate units. If the Marine Corps continues to rely on legacy communications for these programs, they could fall short of meeting the information needs of the next war. New technologies, such as the ones evaluated in this research project, should be seriously considered to keep the warfighter one step ahead of the enemy. The authors looked at UOC, CAC2S, and CoNDOR and how to improve line-of-sight (LOS), beyond line-of-sight (BLOS), and over-the-horizon (OTH) communications for these programs.

The ultimate goal of this research project was to introduce different technologies that could offer more flexibility, mobility, and capability at the tactical level compared to current legacy equipment. These new technologies could provide the Marine Corps with a tactical wireless edge, which could prove to be essential in the future combat missions. To address the issues of the UOC, CAC2S, and CoNDOR programs, the authors conducted four field tests. Field Test One was used to familiarize the students with networking, data collection, and develop interactions with commercial vendors. Field Test Two through Four then addressed the issues of the different programs mentioned above. The combination of all the field tests enabled the authors to become better suited to draw the following overall conclusions for each program.

A. UOC

The planned intra-nodal connectivity between COC and Antenna Hill for the UOC system will be via fiber optic cable. Furthermore, the inter-nodal communication between UOCs will be via MRC-142, satellite communications, or LOS radios. The inter-nodal connectivity needs to be explained further due to the different levels of COCs. First, the battalion level COC, called CapSet IV (see Chapter 1 for further information), is still relying upon LOS and UHF SATCOM radios to talk to senior and subordinate units. Division and regimental level COCs, called CapSet II and III (see Chapter 1 for further information) respectively, are using the MRC-142, satellite communications, and LOS radios to communicate with senior and subordinate units. The Marine Corps understands the vulnerabilities of relying on LOS radios and MRC-142 vehicles for data and voice connectivity. During Operation Iraqi Freedom (OIF), the Marine Corps regiments and divisions relied much more on satellite communications to maintain connectivity since LOS equipment was outran. Consequently, alternative methods need to be pursued instead of running cable in intra-nodal scenarios and using LOS equipment for inter-nodal communications. Several viable commercial technologies were examined in this thesis that warrant further evaluations for UOC use.

The following technologies were examined for potential use in the UOC intra-nodal scenario (COC to Antenna Hill): FSO, Microwave, OFDM, 802.16, and 802.11b over SecNet-11. The FSO, Microwave, and 802.16 equipment evaluated did not have any encryption built into the products. Both OFDM companies were capable of limited encryption that was built into the equipment. The Harris SecNet-11 gear utilizing 802.11b is certified for Type 1 encryption, but the SecNet-11 testing did show a significantly lower throughput than all the other technologies (1-2 Mbps). This may be enough to support the battalion level (CapSet IV) setup, however further testing needs to be conducted to verify this.

When using the KG-235 with the FSO, Microwave, and OFDM products, the throughput only reached up to 5 Mbps. However, this was due to the firmware load on the KG-235. The KG-235 is capable of sending data up to 60 Mbps. The authors were unable to assess 802.16 with the KG-235 due to time limitations. All of these technologies are viable wireless means in the intra-nodal setup. The inherent problem with using the bulk encryptors is the cost of having to employ two (one at each end) of the wireless equipment. While units can save time, be more flexible, and enjoy more safety, the cost of the wireless equipment and encryptors could outweigh the benefits.

In the inter-nodal scenario, CapSet IV units are planned to rely upon current LOS radios such as EPLRS and SINCGARS to exchange data with subordinate units when UOC is fully fielded. This research did bring to light many alternatives that can be explored for more effective communications. The Joint Tactical Radio System (JTRS) will in effect alleviate some of the current throughput limitations, but that program is still several years away from being implemented. There is currently no need for an abundant amount of bandwidth at the lower levels, but the information age has no boundaries. And therefore it is ideal that units at even the lowest level have video and imagery capabilities. As a result, high throughput technologies that were examined could be packaged more appropriately for units on-the-move and in manpack size devices to provide the throughput capabilities to receive large files in an expedient manner. For example in LOS situations, FSO, Microwave, and OFDM equipment can be packaged into one carrying case that can be set up within minutes. OFDM technology is the most versatile as it can be used anywhere throughout the battlefield in LOS and BLOS scenarios and with any size units.

For CapSet II and III, the need for equipment that can be set up and torn down in an expedient manner became more and more prevalent during OIF. BLOS and OTH technologies ruled the battlefield as units outran LOS communications. While most units relied upon Blue Force Tracker to maintain situational awareness on-the-move and SMART-T for satellite connectivity while stationary, this research showed other options available that could significantly improve the abilities of units to maintain the Common Operational Picture on-the-move and exchange data more rapidly when communicating COC to COC. INMARSAT showed its versatility and reliability while employed on-the-move. It can attain throughput rates up to 64 Kbps with improvements possibly reaching 256 Kbps. Broadband satellite services can reach almost five times the throughput of SMART-T's capabilities. However, the cost of employing these technologies can be expensive, and this may warrant a cost-benefit analysis for future studies.

An alternative method to communicate between COCs is to utilize airborne assets to retransmit signals across large distances. Several technologies can be used to accomplish this task, yet the equipment and antenna need to be small enough to be employed on the aircraft. In this research study, 802.11b was retransmitted and the equipment was inherently small enough to put in an airborne package. OFDM would be a viable option to put airborne but the distance remains in question because the signal may not be able to be amplified.

Due to the security issues of wireless communications between COC and Antenna Hill, the Marine Corps may be reluctant to go wireless since fiber cable can provide high throughput and is a secure means of transferring data. However, General Dynamics is recommending a technology insertion to the UOC program to pursue a possible wireless connection between COC and Antenna Hill. Next, the ability to talk BLOS/OTH is becoming more and more of a priority for the Marine Corps. The UOC CapSet II and III will benefit most from the Broadband satellite, OFDM, and aerial relays evaluated in this research as means to supplement or replace the MRC-142 vehicle for LOS communication and SMART-T for OTH situations. INMARSAT and Iridium technologies may be the answer of choice for communications on-the-move.

B. CAC2S

The present plan for CAC2S is to connect the intra-nodal sites by heavy-duty fiber optic cable. In order to provide redundancy, all the sites would be connected with fiber in a token-ring fashion. However, the setup could still be vulnerable since it relies on the cumbersome and time-consuming tasks of laying and burying wire. On the other hand, fiber allows the transmission of secure data due to the inherent security of data being contained within the fiber. As wireless technologies are studied for potential use in an intra-nodal scenario, decision makers need to be aware that the data is now in the open and must be encrypted with a device that is comparable to sending data through the fiber. A bulk encryptor can accomplish this, much like the KG-235 used in this research, or the wireless equipment would need security built into it.

The following technologies were examined for potential use in the CAC2S intra-nodal scenario: FSO, Microwave, OFDM, 802.16, and 802.11b over SecNet-11. FSO, Microwave, and 802.16 equipment evaluated did not have encryption built into the products. For the OFDM equipment, Redline Communications has 64-bit encryption built-in and Alvarion is capable of AES encryption. NSA certifies the Harris SecNet-11 gear utilizing 802.11b for Type 1 encryption, but SecNet-11 testing did show a significantly lower throughput than all the other technologies (1-2 Mbps). When using the KG-235 with the FSO, Microwave, and OFDM products, the throughput only reached up to 5 Mbps. However, this was due to the firmware load on the KG-235. It is capable of reaching 60 Mbps with the right firmware load. Due to time constraints, the authors were unable to assess 802.16 with the KG-235.

The current CAC2S inter-nodal structure uses a combination of MRC-142 and TRC-170 systems. The MRC-142 is strictly LOS with a maximum throughput of 576 Kbps and the TRC-170 can extend out to 100 miles with a maximum throughput of 4.6 Mbps. Since there are not enough TRC-170s for each node located throughout the battlefield, MRC-142s are employed with retransmission sites set up on top of hills or mountains when LOS cannot be attained. The MRC-142 and TRC-170 already employ wireless means between sites, so the research conducted by the authors looked for wireless technologies that could significantly increase the throughput between CAC2S sites while also minimizing the physical footprint.

Several technologies were looked at for a CAC2S inter-nodal setup since there can be LOS, BLOS, and OTH requirements in this scenario. This all depends on the terrain, location, and movement of the CAC2S units. The technologies examined were FSO, Microwave, OFDM, 802.16, and 802.11b over SecNet-11. Each of these technologies was successfully tested at 6.7 kilometers. FSO was more challenging to align due to the narrow laser beam transmitted. Microwave, OFDM, 802.16, and 802.11b over SecNet-11 (amplified) demonstrated the potential to reach long distances if LOS was maintained.

When evaluating BLOS technology, the authors reviewed OFDM. These products can reach out to approximately 20 kilometers in a BLOS scenario, while demonstrating the ability of communicating over hills, around buildings, and through trees. This technology changes the dimensions of inter-nodal communications because units could possibly eliminate the need for a retransmission site. In addition, tremendous flexibility on antenna placement is attained.

INMARSAT and Broadband satellite were evaluated for their OTH capability. INMARSAT throughput capability is too small for CAC2S inter-nodal use, but it could be effective when CAC2S nodes start to displace and need to maintain connectivity on-the-move. The broadband satellite capability could reach up to 9 Mbps and its footprint is considerably less than the TRC-170, so it does have serious potential to replace or augment the TRC-170 for use within the CAC2S architecture. Both INMARSAT and Segovia's Broadband satellite services are capable of NSA Type 1 encryption.

All of these technologies (FSO, Microwave, OFDM, 802.16, 802.11b over SecNet-11, Broadband satellite, and INMARSAT) have a limited power draw of less than 20 Watts, which means that the equipment can draw power off a generator that is providing support to other gear. The MRC-142 and TRC-170 always come with their own generators, thus making the footprint larger. While work remains to be done to ensure that these wireless technologies are compatible within a military environment, these commercial options improve throughput, minimize footprints, and require less power. All of these characteristics certainly would improve the way CAC2S deploys to the field. Recommendations for the CAC2S program can be found in the next chapter.

C. CONDOR

The problem inherently in the CoNDOR setup is that legacy LOS radios and eventually JTRS are being relied upon to provide data connectivity down to the lower levels. These are all limited in throughput capabilities. For example legacy radios provide less than 56 Kbps of throughput and JTRS is below 2 Mbps. While the 2 Mbps throughput is sufficient, JTRS will not be fielded until 2008 and beyond, and it is an unproven concept. The satellite communications being considered to connect the POP vehicle to higher headquarters is also limited in throughput (around 1 Mbps). Several LOS and BLOS technologies evaluated in this research are viable options to connect the CoNDOR POP vehicle to subordinate units. In addition, several technologies were evaluated to connect the POP vehicle to senior units in a BLOS or OTH scenario.

The CoNDOR scenario covers the whole range of communication scenarios, LOS, BLOS, and OTH. Squads, platoons, companies, and battalions maneuver so quickly that they could be in any of these communication situations within minutes. Thus, an integrated architecture needs to be adapted where all the nodes connecting to the POP can talk with each other, ensuring continuous connectivity with the POP at battalion headquarters. This type of architecture is currently very difficult to achieve with the legacy radios employed, since all of them currently rely upon LOS. If a communications architecture can be developed similar to Field Test Four, then units can take advantage of reliable connectivity and increased throughput from the new technologies. This can be done while on-the-move and when traversing over hills, between buildings, and through trees. OFDM and airborne relays are two key technologies that can transform communications for ground units on the battlefield, since the technologies do not require stringent LOS.

Connectivity from the POP vehicle to higher headquarters in the CoNDOR scenario will most likely happen via satellite, although if close enough, BLOS scenarios may apply. The Broadband satellite services by Segovia/Omega Systems should be seriously considered for possible use on the CoNDOR POP vehicle. The equipment can be mounted on the vehicle and is versatile as far as network employment. Private network connection, Internet, and phone services can all be provided. Alternate means of connectivity from the POP vehicle to higher headquarters can be achieved through airborne relay methods. The platform can either relay directly between the two sites, or the platform can relay the signal into space where it can enter the satellite ring and be routed to any location in the world. This is a much more complicated scenario as there are several points of failure in the air as well as on the ground. If the POP vehicle is within 20 kilometers of its higher headquarter, most likely a regiment, then the OFDM technology can be employed, eliminating the need for expensive satellite services.

Many lessons can be learned from OIF as the Marine Corps outran their LOS radios. As CONDOR evolves and is adopted by the Marine Corps, those same tactical radios that failed to provide connectivity in OIF may again be insufficient for the CoNDOR scenario. As the Marine Corps continues to find ways to utilize existing equipment, this research opens doors to proven commercial off-the-shelf technologies that the military can further examine. If OFDM is packaged correctly for the appropriate sized units, then this technology can truly integrate units and be a reliable source to connect to the POP vehicle. Employing the technology airborne could further enhance the potential of ConDOR. The price of employing OFDM is fairly reasonable, but the need for encryption may drive up the cost. Whatever the cost may be, this technology could revolutionize communications in the Marine Corps.

Since the use of wireless equipment introduces a potential security problem to DoD infrastructure networks, DoD Directive 8100.2 was published on 14 April 2004 to address these issues. The encryption of unclassified data for transmission to and from wireless devices is required. Data encryption must be implemented end-to-end over an assured channel and shall be validated to meet the requirements of FIPS PUB 140-1. This applies to all commercial wireless devices, services and technologies including both voice and data capabilities that include commercial wireless devices capable of storing, processing, or transmitting information.[65] Furthermore, Marine Administrative (MARADMIN) message 032/2004 was released on 23 January 2004 based on guidance from the DoD Chief Information Officer. This MARADMIN stated that all Marine Corps information technology developed, acquired, or procured would be IPv6 capable. This is to help the Marine Corps transition to IPv6 by 2008 in order to achieve net-centric operations and other warfare goals. In addition, this will help to minimize costs during the transition period from IPv4 to IPv6.[66]

Based on guidance from DoD Directive 8100.2, the need for encryption becomes a serious concern as commercial technologies are embraced by the military. Since most commercial off the shelf technologies are not equipped with Type 1 encryption, separate devices need to be used to encrypt the traffic going through commercial devices. This raises the costs of procuring new equipment, so a cost-benefit analysis needs to be done to determine if the capabilities of the gear compared to legacy equipment outweigh the costs of procuring the gear. Some of the companies do have encryption techniques built into their products such as AES, but further analysis needs to be done to verify that this meets the standard to transmit classified traffic. Overall, a requirement could be given to a commercial company to pursue building Type 1 encryption into their products. In turn, this could significantly raise the cost.

As seen in MARADMIN 032/2004, Marine Corps networks will follow the IPv6 standard by 2008. This reinforces why the students chose to demonstrate a fully IP based network in all testing events. The UOC and CAC2S programs are also pursuing IP based

---

[65] DoD Directive 8100.2, "Use of Commercial Wireless Devices, Services, and Technologies in the Department of Defense (DoD) Global Information Grid (GIG)", 14 April 2004.

[66] MarAdmin 032/2004, "Marine Corps Internet Protocol Version 6 (IPv6) Policy", 23 January 2004.

networks for their systems. There are numerous benefits of being IP based that the students identified during this research. First, voice, video, and data can all be sent over this one protocol. This ensures a common standard across the network in which information can be easily shared among all users. During Field Test Four, the students were able to demonstrate multiple technologies across eight subnets. These technologies were compatible as long as the equipment supported an IP network. This allowed for a tremendous amount of flexibility for new technologies that could be interfaced in a CoNDOR scenario. In addition, if the UOC and CAC2S use VoIP phones and laptops to move away from switch-based equipment for telephones, a much smaller footprint for each node would be required. Furthermore, CoNDOR will benefit tremendously if every device used to transfer data can be assigned an IP address.

In conclusion, the authors introduce different technologies that offer more flexibility, mobility, and capability for communications on the tactical battlefield. Throughout this research study, the focus revolved around testing equipment and network configurations in an IP network in order to demonstrate a tactical wireless edge. Special consideration was given to wireless issues for the UOC, CAC2S, and CoNDOR, which could improve line-of-sight, beyond line-of-sight, and over-the-horizon communications for each program. These new technologies will transform communications in the United States Marine Corps for the 21st century.

THIS PAGE INTENTIONALLY LEFT BLANK

V. RECOMMENDATIONS FOR UOC, CAC2S, AND CONDOR

A. WHAT CAN BE IMPLEMENTED NOW

Initial guidance from Marine Corps Systems Command was to examine technologies that could be implemented into UOC, CAC2S, and CoNDOR 'now' as well as in the future. For the 'now' portion of the write-up, the authors decided to combine the UOC and CAC2S recommendations since the command and control systems have similar distance requirements when physically deployed on the battlefield and the requirements for communications on-the-move are also very much alike. CoNDOR's recommendations were kept separate since it is not a command and control system but rather a concept of connecting multiple echelons of command together. Table 43 below is a quick reference guide summary of recommendations for the three programs. For UOC and CAC2S, there are four functional areas that communications requirements can fall under: intra-nodal, inter-nodal, communications on-the-move, and aerial relay. The CoNDOR concept revolves around the Point of Presence Vehicle (POP-V) so the functional areas were outlined as follows: into POP-V, out of POP-V, communications on-the-move, and aerial relay.

The ranking system used to prioritize the recommendations for each type of category (line-of-sight (LOS), beyond line-of-sight (BLOS), and over-the-horizon (OTH)) within the physical structure breakdown of the programs is straightforward. The number "one" depicts the first recommendation out of all the technologies. Each subsequent number up to five delineates the second, third, fourth, and fifth recommendations. Ranks were assigned subjectively by the authors based on the results of the tests, the requirements of the systems, and the author's experience.

UOC/CAC2S	FSO	MICROWAVE	802.16	OFDM	BROADBAND SATELLITE	INMARSAT	IRIDIUM	802.11b over SecNet-11
INTRA-NODAL								
LOS	1	2	4	3				5
BLOS				1				
INTER-NODAL								
LOS	4	3	2	1				5
BLOS				1	2	3	4	
OTH					1	2	3	
COMMS ON THE MOVE								
Within the convoy				1				2
Outside the convoy				3		1	2	
For short/long halts, refer to Inter-Nodal BLOS/OTH section								
AERIAL RELAY (UAV/BALLOON)				2				1
CONDOR	FSO	MICROWAVE	802.16	OFDM	BROADBAND SATELLITE	INMARSAT	IRIDIUM	802.11b over SecNet-11
INTO POP-V								
LOS	1	2	4	3				5
BLOS				1	2	3	4	
OUT OF POP-V TO MSC								
BLOS				1	2	3	4	
OTH					1	2	3	
COMMS ON THE MOVE								
Within the convoy				1			3	2
Outside the convoy				3		1	2	
For short/long halts (BLOS)				1	2	3	4	
AERIAL RELAY (UAV/BALLOON)				2				1
Ranking of technologies for each program (1 = first recommendation, 2 = second recommendation…)								

Table 43. UOC, CAC2S, AND CONDOR RECOMMENDATIONS

1. UOC/CAC2S

a. Intra-Nodal

By utilizing wireless technologies to link a Command Center to Antenna Hill within a UOC node or from Processing and Display Subsystem (PDS) to Communications Subsystem (CS) and Sensor Data Subsystem (SDS) in a CAC2S node, the Marine Corps could potentially replace fiber cables that run between the sites. This will enable a quicker setup and tear down of equipment, which would then enable a unit to be more flexible and mobile. In addition, the possibility of cables being damaged by vehicles and equipment would be eliminated, and Marines would not have to spend time digging trenches to bury fiber cable as they do now.

The intra-nodal setup is divided into two different categories for communications, LOS and BLOS. While antennas will most likely sit in some type of defilade, the wireless communications equipment could be easily placed on top of the hill to obtain LOS with the COC or PDS for UOC and CAC2S respectively. Since another technology was explored in this research that would allow connectivity to be established while the two antennas were not in sight of each other, there is the BLOS connectivity recommendation for the intra-nodal scenario.

The LOS technologies researched for the intra-nodal setup in the order of recommendation are as follows: Free Space Optics (FSO), Microwave, Orthogonal Frequency Division Multiplexing (OFDM), 802.16, and 802.11b over SecNet-11. FSO is the right fit for a short distance of less than 2 kilometers. There are various benefits to using this technology: throughput comparable to fiber cable speeds, operates in a license free spectrum, enjoys a quick set up and tear down time, and is not as susceptible to weather at a short distance. While the Microwave product, Radio Frequency Module, examined for this thesis had comparable characteristics to the FSO product with better distance capabilities and less vulnerability to atmospheric conditions, it required a license to operate in the 14-15 GHz range. This would not be an issue during a time of war, but when training with it throughout the world there could be problems obtaining frequency use. In addition, the transmitting beamwidth is much greater than FSO; therefore, making microwaves more susceptible to interception. Next, OFDM and 802.16 have less throughput capability than FSO and Microwave. OFDM can operate in the 5 GHz license free spectrum and has limited built in encryption, while 802.16 requires a frequency license to operate the equipment. Finally, 802.11b over SecNet-11 has a powerful capability of National Security Agency (NSA) certified Type 1 encryption built into the cards. Therefore, no external encryption device would is needed to utilize this equipment. The downside of the SecNet-11 equipment is that the throughput of 802.11b is severely limited compared to the other broadband technologies. The 1-5 Mbps attained would not be enough to replace a cable run between sites, which can currently run at gigabit speeds.

OFDM was examined and evaluated throughout this thesis research at various field tests. OFDM has a distinct advantage of being placed in valleys near Antenna Hill, where it can be camouflaged without inhibiting the capacity of the link. The throughput of the technology can vary considerably, but it is capable of reaching up to 72 Mbps. The authors only saw throughput up to 24 Mbps, however, when in non-line-of-sight situations. A significant benefit of this equipment is that it is small and requires minimal power. The 20-30 Mbps range would be sufficient to support the link between Command Center and Antenna Hill for the UOC and CAC2S. Even though this was the only technology examined for BLOS situations, no other technologies are known that can offer this type of flexibility unless satellite communications are employed. The use of satellites would not be practical for the intra-nodal scenario. Therefore, OFDM is the only recommended BLOS technology for both UOC and CAC2S in the intra-nodal setup.

b. Inter-Nodal

The UOC program will continue to utilize legacy systems to provide connectivity between UOC nodes located throughout the battlefield. At the regiment, the MRC-142 vehicle can provide LOS connectivity. Below the regiment level, tactical radios such as Enhanced Position Location Reporting System (EPLRS) and Single Channel Ground-Air Radio System (SINCGARS) will continue to be utilized until the Joint Tactical Radio System (JTRS) is fielded. At the regiment, for BLOS and OTH capability, Secure, Mobile, Anti-Jam, Reliable Tactical Terminal (SMART-T) will be employed as well as receive only Global Broadcasting Service. There is currently no BLOS/OTH capability below the regiment except for PSC-5 UHF SATCOM radios. Next, CAC2S will rely on two primary methods of transmitting data between nodes on the battlefield, MRC-142 and TRC-170. Despite their capabilities, these legacy systems have some shortfalls. The MRC-142 has limited bandwidth with LOS distance capabilities of up to 35 miles, and the TRC-170 has a major footprint to go along with a significant power requirement. The technologies examined can provide significant improvement in throughput, a smaller footprint, and a smaller power requirement over the legacy equipment planned for employment with UOC and CAC2S systems.

Since the distances between UOC and CAC2S nodes are unpredictable due to the frequent movement of units on the battlefield, the three communications scenarios, LOS, BLOS, and OTH, could all be encountered at any given time. The LOS scenario is rated quite different that the LOS setup for intra-nodal communications. In order of ranking, the following technologies are recommended for use in LOS situations for the inter-nodal scenario: OFDM, 802.16, Microwave, FSO, and 802.11b over SecNet-11. When LOS can be attained between two UOC/CAC2S nodes, it is likely the distance will be greater than 5 kilometers and the terrain will not be perfectly flat. OFDM is best suited for this type of setup since it is the most forgiving of the technologies if ideal LOS is not attained. The reason to recommend 802.16 technology over Microwave is that 802.16 can reach out to 20 kilometers while the high throughput microwave is limited to 13 kilometers. Next, FSO is designed for distances of less than five kilometers. While it was shown to function up to seven kilometers and most likely further than that with ideal weather conditions, bad weather would reduce the quality of communications obtained at further distances. 802.11b over SecNet-11 is recommended last because of its low throughput as distances increase, and it is vulnerable to denial of service since it operates in the well known 2.4 GHz range.

OFDM can operate in LOS or BLOS situations. This makes the technology the number one recommendation for inter-nodal BLOS scenarios. OFDM can maintain connectivity over hills, through trees, and around buildings. In addition, the cost to purchase the equipment is under $5k, which makes it relatively inexpensive. No other technologies were examined that could provide terrestrial BLOS connectivity; therefore, satellite connectivity was rated against OFDM in the BLOS category. The second, third, and fourth recommendations are as follows: Broadband satellite, INMARSAT, and Iridium respectively. These are also in the same order for OTH communications in the inter-nodal scenario. Broadband satellite provided by Segovia/Omega Systems can replace the TRC-170 setup for CAC2S with its capabilities to reach up to 9 Mbps, and it is comparable in size with the SMART-T system but could provide more throughput capability for the UOC node. INMARSAT and Iridium are ranked lower because the throughput capabilities for the inter-nodal setup are insufficient to support the requirement for the nodes. INMARSAT is also much more expensive than Broadband satellite. These two technologies will be discussed in the communications on-the-move section when they are more applicable.

c. Communications on-the-Move

Communications on-the-move can no longer be overlooked for the UOC and CAC2S nodes since forward echelons must be sent out when displacing. This forward echelon is used to taking control when the main node begins to displace. While the forward echelon is displacing, they need to keep situational awareness to assist in the turnover from main to forward. This situational awareness usually comes in a digital format. So, if connectivity is lost then vital time could be wasted trying to pass updates from the main to the forward echelon. Communications on-the-move is broken down into three categories which are listed as follows: within the convoy, outside the convoy, and short/long halts.

(1) Within the Convoy. The communications that are utilized within the convoy link all the vehicles together to exchange information. One vehicle within the convoy will maintain connectivity with other units outside the convoy. Single-channel voice communications are currently maintained but data connectivity is quite limited. If a limited network is set up within each vehicle, and each is outfitted with the appropriate antennas, then the whole convoy can maintain high throughput connectivity via OFDM or 802.11b over SecNet-11. OFDM has the highest recommendation since LOS does not need to be maintained while the vehicles are moving. Each vehicle can remain a safe distance away from the others, which ensures a good security posture. The OFDM technology can connect the convoy by placing a sector antenna in the lead vehicle while all others maintain an omni-directional antenna (other options could be employed). 802.11b over SecNet-11 can work as long as LOS is sustained while the vehicles are in motion. Most likely omni-directional antennas and amplifiers would need to be utilized for this purpose. The cost for both of these setups would be very similar.

(2) Outside the Convoy. While the distance and terrain can vary greatly when communicating from a forward echelon convoy back to the main, some type of satellite connectivity that can function on-the-move would be needed. INMARSAT and Iridium were examined for this capability. INMARSAT's throughput capabilities are far superior to the limited throughput of Iridium. Therefore, INMARSAT is recommended over Iridium despite the lower cost of Iridium. If within a 10-20 kilometer radius, the convoy could maintain connectivity with the main terrestrially through the use

of OFDM. The antennas on the vehicle and with the main would need to be omni-directional, which would decrease the distance OFDM could operate. OFDM is the last recommendation due to the distance limitation, but it is still an option since terrain becomes less of an issue with this technology.

(3) For Short/Long Halts. While communications on-the-move is vital, it is also important to recognize that there may be times when short or long halts of a convoy are needed. Thus, some type of quick setup is needed for connectivity from the forward echelon to the main. The communications within the convoy can stay per the recommendations earlier, as vehicles can maintain an effective security posture and stay BLOS from each other. If the convoy was using INMARSAT as the communications connectivity for on-the-move, then this may remain sufficient for a short halt. However, during a lengthy halt, it may prove useful to set up Broadband satellite connectivity for more throughput capability. The Segovia/Omega Systems equipment can self-acquire the aerial satellite; therefore, connectivity could be established within minutes.

d. Aerial Relay

The use of aerial relays for UOC and CAC2S nodes can greatly increase inter-nodal communications. This could be an alternative to the MRC-142 or TRC-170, as the 802.11b over SecNet-11 could be retransmitted via the aerial platform for hundreds of miles if the signal was amplified and appropriate antennas were utilized. If it is determined that OFDM can be amplified, then distance could equal that of 802.11b and greater flexibility is attained on where antennas would need to be placed on the ground to maintain connectivity with the aerial platform. Since 802.11b was tested and has proven to work over great distances, this technology is the first recommendation. More research needs to be conducted with OFDM to determine the validity of using it as a technology in an aerial relay platform.

2. CONDOR

a. Into POP-V

The current plan for the CoNDOR scenario is to place a Point of Presence Vehicle (POP-V) at the battalion level to further enhance the capabilities of the subordinate units with low throughput capabilities. This vehicle will allow those units with EPLRS, SINCGARS, HF, HF Automatic Link Establishment (ALE), and UHF

SATCOM to have access to Major Subordinate Commands (MSCs) through the satellite connectivity at the battalion level. While this research looked at transformational communication technologies for the UOC and CAC2S, these type of scenarios are mostly stationary with the need to connect a relatively large node. For the CoNDOR scenario, the situation is much more unique as units could be stationary one minute and on-the-move the next. In the traditional structure of a battalion, the company headquarters may be stationary long enough to incorporate what is recommended for the UOC and CAC2S program. Thus, the LOS recommendations for the communications into the POP-V resemble the LOS rankings used for UOC and CAC2S. Since EPLRS is currently the best form of data connectivity down to the lower levels at 56 Kbps, it is obvious that the technologies recommended would bring a new kind of capability down to the lowest level. The following technologies are recommended for LOS into the POP-V in the order of preference: FSO, Microwave, OFDM, 802.16, and 802.11b over SecNet-11.

The first recommendation for LOS communications is to use FSO, which has a throughput capability ranging from T1 (1.5 Mbps) up to Gigabit speeds (1000 Mbps). The setup is scalable to the size of the unit, and the time to establish connectivity with the POP-V could be within minutes. The microwave product examined can also vary the data rate from T1 (1.5 Mbps) but only up to OC-3 speeds (155 Mbps). This setup is more cumbersome to the user and frequency licensing is an issue during peacetime. Next, OFDM is a relatively quick and simple setup. The throughput capabilities are much more limited compared to the other technologies (up to 72 Mbps), but OFDM is much more effective in BLOS situations when compared to the other technologies. 802.16 could be a nice fit communicating into the POP-V as it can provide connectivity in a 360-degree range, but it is limited to less throughput than OFDM at roughly 66 Mbps. Finally, 802.11b over SecNet-11 is much more flexible in the changing environment from stationary to mobile, and it has Type 1 encryption built in. The equipment also creates a small footprint, but the throughput is limited to 1-5 Mbps depending on the strength of the signal.

For BLOS situations when communicating from the lower echelons to the POP-V, the following technologies are recommended in order of preference: OFDM, Broadband Satellite, INMARSAT, and Iridium. OFDM can become the technology of the future for the Marine Corps if it can be properly encrypted in a cost effective manner. The ability to communicate over hills, through trees, and around buildings can allow the subordinate units communicating with the POP-V to maintain an effective security posture while still achieving high throughput capabilities up to 24 Mbps. Broadband satellite connectivity can be packaged in a suitcase size unit, but the cost of using the services at such low echelons may be unrealistic. INMARSAT and Iridium provide no greater increase in throughput over the current LOS radios, but they do offer the flexibility to talk BLOS/OTH.

b. Out of POP-V to MSC

When communicating from the POP-V to an MSC, the scenario will most likely require some form of BLOS or OTH connectivity. The distance is unpredictable enough that some form of satellite connectivity is needed at this site to attain the required communications to the MSC. INMARSAT or some form of TACSAT can provide that connectivity, but the Marine Corps is looking for commercial products that can augment this need. During the various field tests, the authors were fortunate enough to be exposed to several leading technologies that can be applicable for the POP-V to MSC requirement. In a BLOS situation, the following technologies are recommended in the order of the authors preference: OFDM, Broadband satellite, INMARSAT, and Iridium. OFDM can provide a terrestrial connection up to 20 kilometers and can reach over hills, through trees, and around buildings. This technology can also be retransmitted if the situation dictates. The next three technologies, Broadband satellite, INMARSAT, and Iridium, were also ranked in the same order for OTH capability.

Segovia/Omega Systems Broadband satellite connectivity during Field Test Four was most impressive. They are able to vary the amount of throughput that is needed and can provide private network capabilities, Internet services, and phone services. Their link can also be Type 1 encrypted, which could provide SIPRNET connectivity. INMARSAT can be employed while stationary, but the cost is just not comparable to what other service providers can offer when stationary. Iridium has a low throughput of up to 9.6 Kbps when combining four Iridium channels. It is recommended last because of the throughput. However, the technology is currently available, as evidenced by its use at the Marine Corps Warfighting Lab for the Expeditionary Tactical Communications System.

c. *Communications on-the-Move*

(1) Within the Convoy. Communications on-the-move is what the CoNDOR architecture is built for. Since current LOS radios can communicate on-the-move, transformational communications needs to be able to replicate this functionality. In order to improve throughput within a convoy of vehicles, which in the CoNDOR scenario may be a company or platoon convoy, several technologies were evaluated for applicability at this level. The recommendations resemble those that were made for UOC and CAC2S since the technologies can be used at any level. The following are the recommendations in order of priority: OFDM, 802.11b over SecNet-11, and Iridium. OFDM will again provide sufficient bandwidth for a platoon/company sized unit, enable a small footprint, and allow vehicles flexibility on where to locate in a convoy. 802.11b over SecNet-11 offers similar benefits but LOS must be maintained between the vehicles. This is the main reason it is ranked second behind OFDM, despite the encryption capabilities of SecNet-11. Innovative methods can be explored to encrypt the OFDM link in a cost effective manner. Finally, Iridium is recommended as the third option for this scenario due to its capability to be used on-the-move, and it could provide a small sized unit in a convoy with a sufficient amount of bandwidth.

(2) Outside the Convoy. This category is most applicable to how units will maintain connectivity with the POP-V while on-the-move. If there is a company or platoon size unit that is traveling in a convoy, then they need to have some means of maintaining connectivity to the POP-V in order to be connected with all other units associated with that POP-V. Again, this mirrors the communications on-the-move section for UOC and CAC2S. INMARSAT is the first recommendation due to the on-board satellite terminal's ability to track the aerial satellite while in motion. This is currently a costly solution, but Marine Corps Systems Command is exploring options to have users share the bandwidth, which in turn would reduce the cost. The second recommendation is to use Iridium due to its being available now and the ability to use it an unlimited amount. In addition, it can be used on-the-move and from anywhere on the battlefield to talk back to the POP-V. The down side is that the throughput offers no

more than the current existing LOS radios. Lastly, OFDM is recommended for communications with the POP-V while on-the-move because of its capability to maintain connectivity over adverse terrain conditions. On the other hand, the distance OFDM can traverse is roughly 20 kilometers without a retransmission site. This is the reason for ranking it last when compared to INMARSAT and Iridium.

(3) For Short/Long Halts. As units maneuver throughout the battlefield in convoys, there will be times when the convoy will make a short or long halts that produce opportunities to establish connectivity while stationary. This then turns into the BLOS scenario that was explained earlier for communications into the POP-V. If within distance of a POP-V, then the number one choice remains OFDM due to its inexpensive cost and unique capabilities. The second, third, and fourth recommendation all depend on satellite communications. These are all going to be more costly, although Broadband satellite could be packaged for smaller units. It can also provide a sufficient amount of bandwidth for a small unit at a justifiable cost. INMARSAT connectivity could possibly allow multiple users to share the 64 Kbps currently offered. If upgrades are accomplished as expected, then there will be more bandwidth to share. Iridium will offer a means to communicate that is already paid for, but the throughput offers no more than the LOS radios. However, Iridium does offer BLOS/OTH voice and data connectivity.

d. Aerial Relay

The use of aerial relays for CoNDOR can greatly increase the ability to communicate from units to the POP-V and from the POP-V to MSCs. This could be an alternative to relying on LOS radios or satellite communications. The two technologies examined in this thesis are recommended for use in the aerial relay platform, 802.11b over SecNet-11 and OFDM. 802.11b over SecNet-11 can be retransmitted via the aerial platform for hundreds of miles if the signal is amplified and appropriate antennas are utilized. If it is determined that OFDM can be amplified, then distance can equal that of 802.11b and greater flexibility is attained at the locations where antennas would need to be placed on the ground to maintain connectivity with the aerial platform. Since 802.11b was tested and has proven to work at various distances, this technology is the first recommendation. More research needs to be conducted with OFDM to determine the validity of using it as a technology in an aerial relay platform.

Several commercial off-the-shelf technologies were examined to determine if they could be implemented into the UOC, CAC2S, and CoNDOR programs within the next few years. Based on this research, the authors developed their recommendations for each program. The research team decided to combine the UOC and CAC2S recommendations since the command and control systems have similar distance requirements when physically deployed on the battlefield and the requirements for communications on-the-move are very much alike. CoNDOR was kept separate since it is not a command and control system, but rather a concept of connecting multiple echelons of command together. Table 44 below was developed by the authors to assist them in making the recommendations for each of the programs. It lists the pros and cons of the technologies that were examined, and recommends how each technology should be employed in the communications scenario (LOS/BLOS/OTH). Table 44 below was the driving factor that assisted the authors in deciding on the recommendations displayed in Table 43 above.

UOC/CAC2S/CoNDOR	Distance	Pros	Cons
FSO	LOS	Fiber throughput speeds, quick setup time, operates in license free spectrum	Susceptible to weather conditions, short distance (< 5 km), laser alignment
MICROWAVE (RFM)	LOS	Up to OC-3 speeds, already packaged, reaches out to 13 kilometers	Obtain authorization for frequency use, susceptible to interception due to RF use
802.16	LOS	Adaptive modulation, up to 66 Mbps, 360 degree coverage out to 20 km	No built-in encryption, company evaluated was ATM based (there are others IP based)
802.11b over SecNet-11	LOS	Type 1 encryption built-in, send up to secret level data, small footprint	Low throughput of 1-2 Mbps, difficult to configure, not compatible with other 802.11b
OFDM	BLOS	Communicates over hills, through trees, and around buildings, 25 Mbps throughput	Limited encryption built in, need good azimuth for BLOS connectivity
BROADBAND SATELLITE (Segovia/Omega Systems)	BLOS/OTH	Large throughput capabilities of up to 9 Mbps, mountable on a vehicle, Type 1 encryption	Annual/Monthly Fees, but not by minute
INMARSAT (Nera)	BLOS/OTH	Satellite connectivity on-the-move, small mountable vehicle platform, encryption	Expensive per minute fees, low throughput of 56 Kbps (working on upgrades)
IRIDIUM	BLOS/OTH	Capable of combining four channels, comms on-the-move, no monthly fees	Low throughput of 2.4 Kbps per channel, difficult to send data without compression

Table 44. PRO/CONS OF EACH EXAMINED TECHNOLOGY

B. WHAT CAN BE IMPLEMENTED IN THE FUTURE

The future holds many possibilities regarding what could be implemented on the tactical battlefield. In order to meet DoD's commitment to Joint Vision (JV) 2020, laser communication will most likely be the leading technology because of its high throughput capability. JV 2020 outlines full-spectrum dominance and network centric warfare, but without lasers that vision is only a dream. In addition, technologies such as Transformational Satellites, Wideband Networking Waveform, Joint Tactical Radio System; and concepts such as Bandwidth Sharing, Quality of Service, and a Joint Integrated Common Operating Picture are critical in a network centric environment. Many efforts are being employed in order to fully develop the Transformational Communications Architecture (TCA). In the following sections three recommendations will be described for the UOC/CAC2S/CoNDOR scenarios, a wireless recommendation will be described in a FORCEnet scenario, and follow-on research recommendations will be discussed.

1. UOC/CAC2S/CoNDOR

a. UAV Laser Communication

Utilizing aerial relay for communications has proven to extend connectivity on the tactical battlefield. The idea of dedicating a UAV for this service is something decision-makers will have to address in the near future. Similar to how aerial relays currently operate, it is proposed for a futuristic transformational communications network that UAV laser communications be utilized in order to enhance the maximum throughput on the tactical battlefield.

The concept consists of a UAV with laser equipment working as a relay into the satellite TCA that will exist in 2015 and beyond. Inside the UAV, there will be several lasers that will have the ability to track moving objects. The laser that is oriented to the sky would be responsible for tracking, sending, and receiving information from the satellite unit. The laser that is oriented laterally would be responsible for tracking, sending, and receiving information from other aerial units. The laser that is oriented to the ground would be responsible for tracking, sending, and receiving information from the ground unit. Utilizing the UAV this way allows it to become an integral part of the TCA.

UAV laser communications is a definite option for future UOC/CAC2S/CoNDOR communications. The suggested application, described above, for the UAV employing laser connectivity among the units on the tactical battlefield can potentially be achieved within the next two decades. A diagram illustrating power to the tactical edge using laser connectivity is shown below (Figure 76).

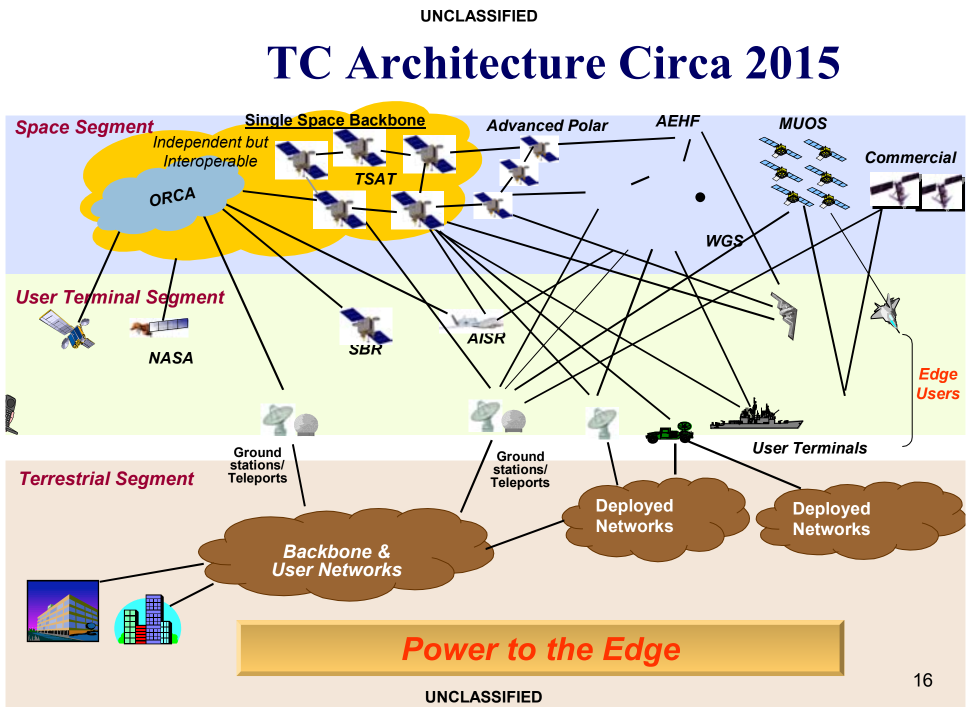

Figure 77. TCA CIRCA 2015 FROM TCA BREIF[67]

The reality of this type of technology and concept is currently being studied. General Atomics Aeronautical Systems, Inc. were funded in 2002-2003 for an engineering task for the Jet Propulsions Laboratory Lasercom Terminal and UAV Laser Communications Project. In addition, according to Free-Space Laser Communications Technologies, a demonstration was conducted from the UAV-to-Ground Lasercomm.[68]

[67] ADM FISHER BRIEF, (SEPT 2003)

[68] Berardo G. Ortiz, Shinhak Lee, Steve Monacos, Malcolm Wright, and Abhijit Biswas, Jet Propulsion Laboratory, Californina Institute of Technology, Pasadena CA, "Design and development of a robust ATP subsystem for the Altair UAV-to-Gound Lasercomm 2.5 Gbps Demonstration" (SPIE, 2003)

This reinforces the idea of being able to use laser communications and UAVs together. Lawrence Livermore National Laboratory in Livermore, CA, is conducting additional work in an attempt to solve the ground to air tracking problem.

b. Long Range, Ground-Based Laser Connectivity

According to Jet Propulsion Laboratories, “a state of the art optical communications telescope laboratory to perform research and development of laser beam propagation and signal detection technologies to meet NASA’s future needs for high-bandwidth communications…”[69] is being examined. This illustrates the seriousness of the capability of laser communications. Another futuristic transformational communications concept is the ability to rely on the unique properties of femtosecond optical pulse in order to increase the current LOS capabilities. The authors recommend further studies into the femtosecond optical pulse capability.

Attochron, LLC; a company based in Los Angeles, CA, specializes in free space optical communications technologies. According to Attochron, “Femtosecond optical pulses can provide a communications bandwidth 1,000 times greater than the current microwave line-of-site technology.”[70] Tom Chaffee, Founder and CTO of Attochron, LCC; elaborates on Attochron’s capability, “Attochron’s free space optical (FSO) communications and power delivery technology utilizes the physics of the leader phase of lightning, air ionization, which allows Nature to transmit tremendous amounts of light and power through Earth’s normally insulative atmosphere. It’s interesting to note that this is possible often while in the presence of inclement weather (fog, clouds, and rain). Attochron uses two ultra fast lasers fired in sequence to achieve ionization of air. The first laser affects an ionized aerial waveguide unaffected by the diffraction of the atmosphere. A second laser, fired immediately afterwards, maintains the stability of the ionized pathway and provides, with its beam, the medium for either communications or power delivery.”[71] The distance this technology can deliver is in the range of 28 km. Studies are currently being conducted to increase the distance and capabilities of this new

[69] K.E. Wilson, W.T. Roberts, V. Garkanian, F. Battle, R. Leblanc, H. Hemmati, and P. Robles, “Plan for Safe Laser Beam Propagation from the Optical Communications Telescope Laboratory” (February 15, 2003).

[70] http://www.attochron.com/ (May 2004)

[71] Tom Chaffee, “Femtosecond Laser Air-Ioniztion for Free Space Optical (FSO) Communications and FSO Power Delivery” (Technical White Paper, Attochron, LLC 2002)

technology. This technology when proven sound could be an excellent fit for the UOC/CAC2S/CoNDOR sites for BLOS scenarios.

c. OFDM in Aerial Relay

A technology that is closer to being usable is OFDM in an Aerial relay. This concept is being studied at the Naval Postgraduate School (NPS) as follow-on research from this thesis. In a series of experiments called Surveillance Target Acquisition Network (STAN), NPS students are taking commercial-off-the-shelf OFDM products to extend the BLOS capabilities in a tactical environment. The method by which this is accomplished is by placing the OFDM technology in a tethered balloon or by placing the technology in an aerial relay.

In the next STAN experiment, OFDM will be placed in an aerial relay in order to increase BLOS capabilities. OFDM's unique wave characteristics yield capabilities for this technology to communicate BLOS. The scenario will consist of a 100-mile distance being covered by an OFDM signal. However, there are concerns that OFDM may not be able to be amplified from the aerial relay. Regardless, one site will be located at NPS (Monterey, CA), while the other site will be in Camp Roberts, CA. The aerial relay will retransmit the OFDM signal between sites. The expected throughput values are in the neighborhood of 10 to 20 Mbps. The capability of passing sensor, voice, and computer data will be tested on the IP-based OFDM backbone. This demonstration is an example of how UOC/CAC2S/CoNDOR can take advantage of commercial-off-the-shelf technology and implement it in a tactical environment in order to communicate in a BLOS scenario.

2. FORCEnet Application

A wireless recommendation in a FORCEnet scenario consists of integrating a call for fire scenario on the tactical battlefield with wireless technologies. In a study conducted by Space and Naval Warfare Systems Command (SPAWAR), Charleston, SC; they addressed this recommended wireless solution for the FORCEnet scenario.

Efforts spear-headed by Dennis L. Gette, code 61B Transformational Science and Technology; have demonstrated a prototype FORCEnet Engagement Package (FNEP) Combat Reach Capability (CRC). The FNEP is a small-scale system that integrates joint sensors, platforms, weapons, networks, and Command and Control (C2) systems. The

CRC is achieved through distributed services available in the FORCEnet cloud via the FNEP. An extract of the demonstration is provided as a recommendation for an integrated transformational network-centric environment for a futuristic UOC/CAC2S/CoNDOR.

SPAWAR-Charleston demonstrated a scaled-down prototype version of a FORCEnet-enabled CRC. The prototype is based on a Call for Fire (CFF) As-Is Operational View (OV). According to Mr. Gette, "The As-Is OA for a USMC CFF is presented as an Operational View (OV-1) in Figure 77. The OV-1 serves to illustrate the sequence of tasks or operational activities that take place as dictated by current Tactics, Techniques, and Procedures (TTPs)."[72] Figure 77 depicts the current call for fire scenario.

[72] Dennis L. Gette, Space and Naval Warfare Systems, Transformational Science and Technology; "Demonstrate a Prototype FORCEnet Engagement Package (FNEP) Combat Reach Capability (CRC)" (Jan 2004)

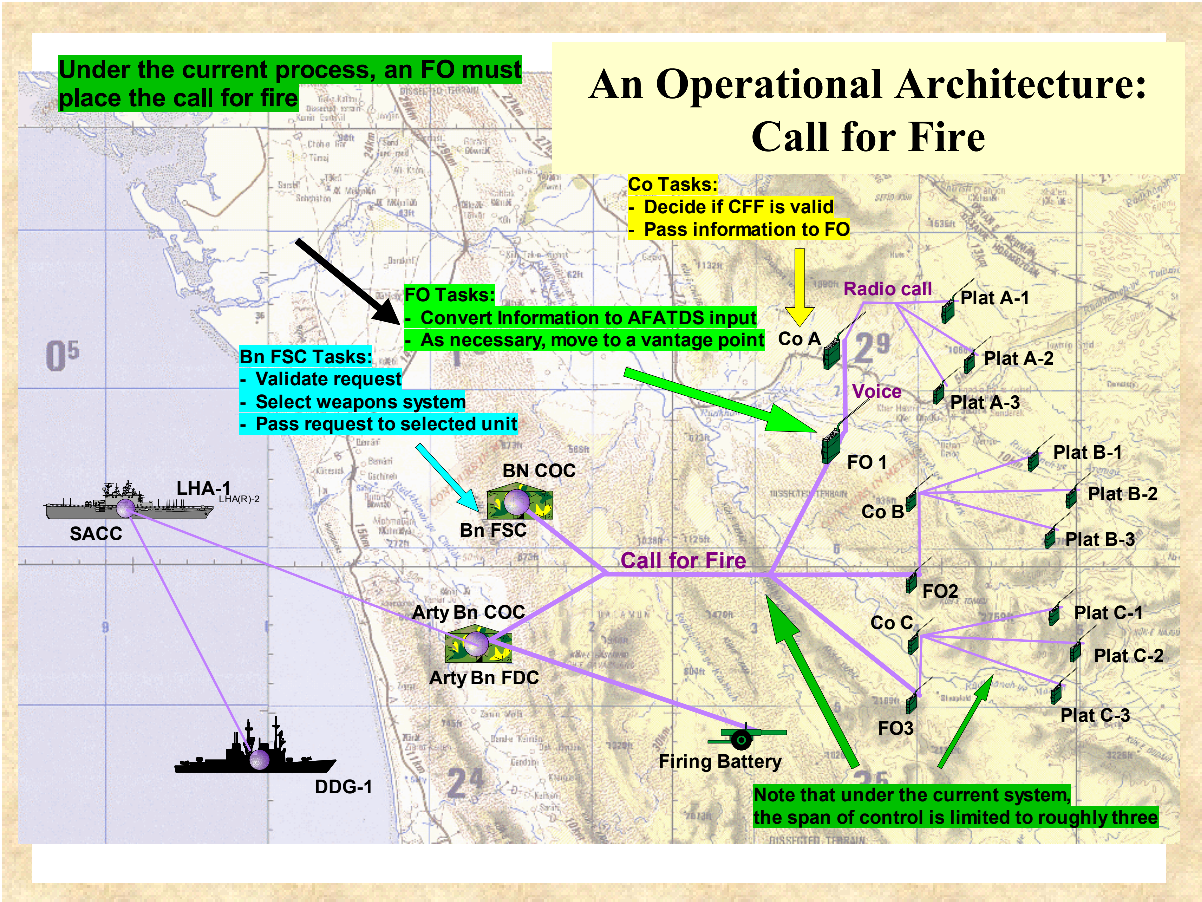

Figure 78. AS-IS CALL FOR FIRE OPERATIONAL VIEW (OV-1)

The current process requires Forward Observers (FOs) and Forward Air Controllers (FACs) to place the call for fire. The FO converts the information to an AFATDS input and passes the input to the Company (Co) level. The CO decides if the call for fire is valid and then passes the information to the Bn. The Battalion Fire Support Coordinator (Bn FSC) passes the input to the Bn CO, who decides if the call for fire is valid. The Bn CO then tasks the Bn FSC to validate the request, selects the weapon system, and passes the request to the selected unit.

A couple of points to take away from the OV-1 are: (1) The task of converting information to AFATDS input is sometimes difficult, suggesting that a sensor should automatically convert the input into useable data. (2) The OV-1 relies on single channel radios to communicate with Co HQ and Bn FSC Center. This connectivity maximizes at 16 kbps, which is low throughput on the tactical battlefield. (3) The final point is the FOs and FACs do not have access to a common operational picture. Current TTPs do not prescribe the need for a common operational picture at that level and many will argue within the operational community that the FOs and FACs do not have the time to look at or use the common operational picture.

According to Mr. Gette, "Under the (unofficial) STOM CONOPS portrayed in Figure 78, platoons can call for fire directly. In this To-Be OV, a different Operational Facility (OPFAC) other than the Bn FSC can validate the CFF, select the appropriate weapons system(s), convert the request to AFATDS format, and pass the request to the selected unit. Notice that the Co only intervenes if the call for fire is inappropriate (e.g., based on a target's value or priority)."[73] The figure below provides an environment for the junior leaders to make decisions based on the Commander's intent. This environment favors centralized command and decentralized control meaning the junior leader is capable of carrying out the Commander's intent with minimal supervision. A network-centric environment should provide higher commands with the capability to pass information down to the lower echelons and promote more efficient, synchronized operations without impacting centralized command and decentralized control. Implementing this approach would require significant changes to existing Tactics, Techniques, and Procedures.

[73] Dennis L. Gette, Space and Naval Warfare Systems, Transformational Science and Technology; "Demonstrate a Prototype FORCEnet Engagement Package (FNEP) Combat Reach Capability (CRC)" (Jan 2004)

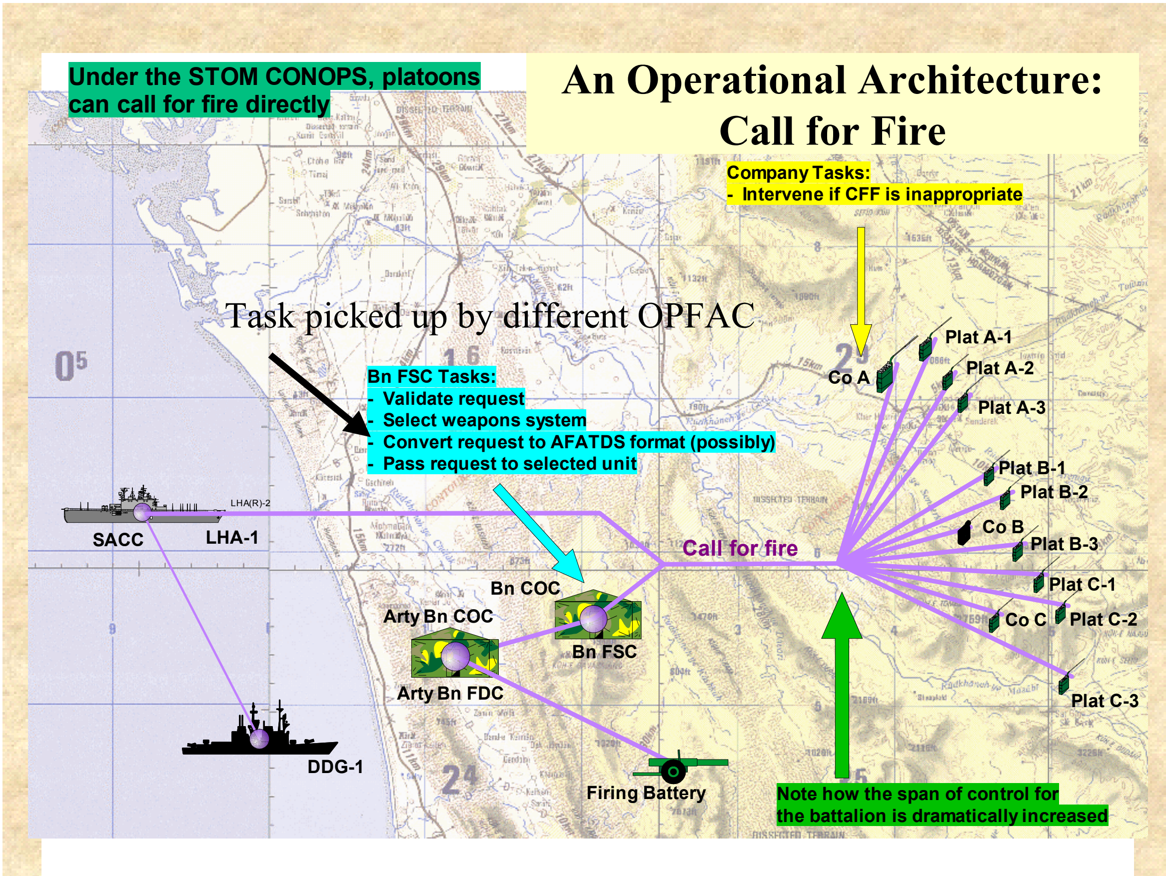

Figure 79. TO-BE CALL FOR FIRE OPERATIONAL VIEW (OV-1)

According to Mr. Gette, "The Fast Ethernet Tactical Network is based on an on-going effort by SPAWAR-Charleston and the USMC to test and evaluate new approaches for improving the mobility and performance of tactical networks that will support the multi-function/multi-mission node-to-node operations of the CAC2S."[74] The Fast Ethernet Tactical Network was used for the prototype experiment. The prototype experiment reinforced the efforts of the current authors because the prototype demonstrated Free Space Optics (wireless technology) as potential solutions for intra-nodal and inter-nodal connectivity for UOC or CAC2S.

[74] Dennis L. Gette, Space and Naval Warfare Systems, Transformational Science and Technology; "Demonstrate a Prototype FORCEnet Engagement Package (FNEP) Combat Reach Capability (CRC)" (Jan 2004)

According to Mr. Gette, "For the limited demonstration shown in Figure 79, an FSO link will be used to distribute a Common Tactical Picture (CTP) from a Command and Control (C2) Producing Node to an FO, Co, or Bn FSCC Consumer Node on the FORCEnet Tactical Internet. By subscribing to an up-to-date CTP, it may be possible for participating units in an Amphibious Assault Operation to coordinate and conduct a Joint Fire Operation on multiple fixed, moving, and aerial targets."[75]

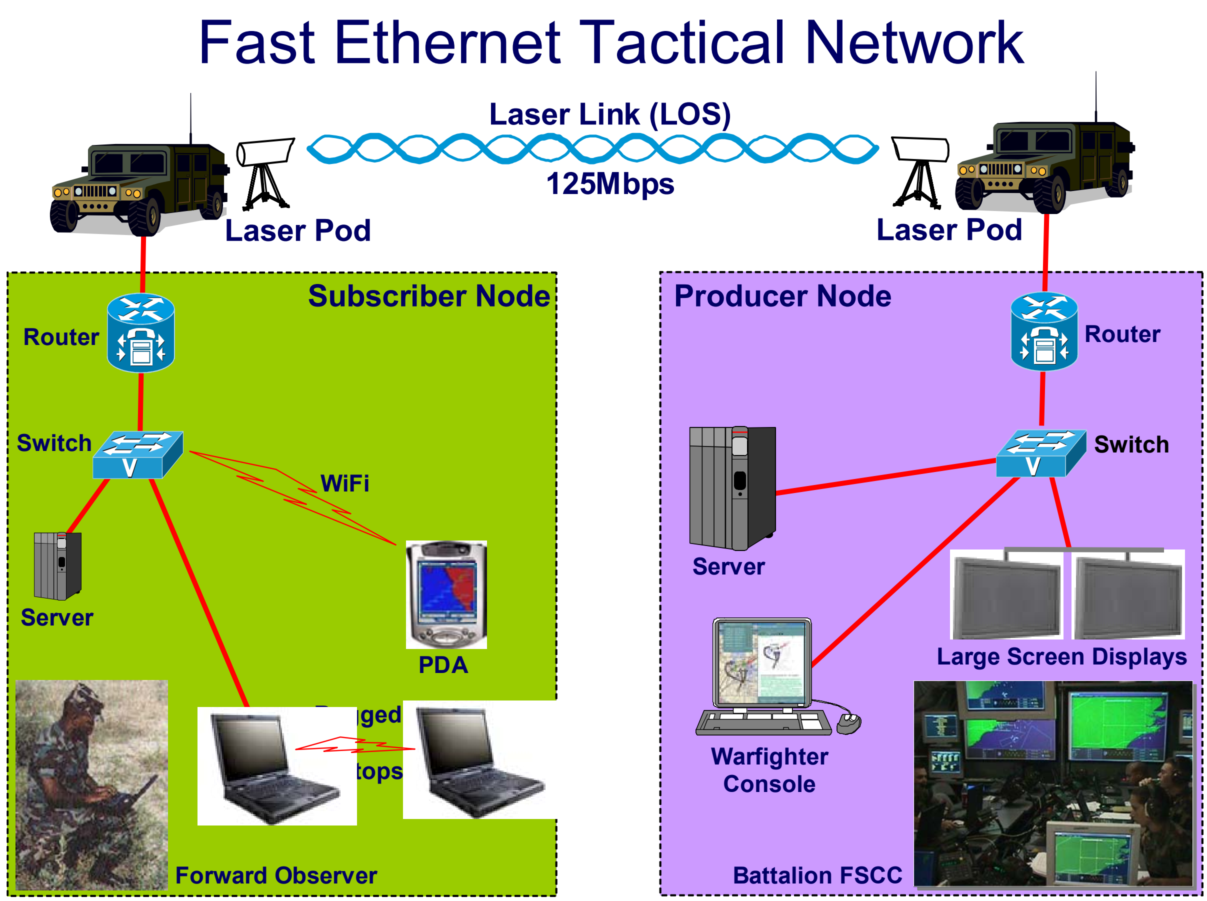

Figure 80. FAST ETHERNET TACTICAL NETWORK

The Fast Ethernet Tactical Network above demonstrated the potential capability of a call for fire scenario. The important factor to extract is that the throughput on the

[75] Dennis L. Gette, Space and Naval Warfare Systems, Transformational Science and Technology; "Demonstrate a Prototype FORCEnet Engagement Package (FNEP) Combat Reach Capability (CRC)" (Jan 2004)

tactical battlefield is currently limited and stove-piped. Through continuous efforts by the FORCEnet studies group and agencies like SPAWAR-Charleston a network-centric environment will be available for the tactical warrior.

Dennis Gette sums it up best by saying, "The bottom line is that bottlenecks and chokepoints between the Ground and Aviation Combat Elements of the MAGTF are common occurrences because of high network loading and low throughput. To further exacerbate this problem are the interoperability challenges that are created by the added complexity of the structure and employment considerations of other Service equipment, agencies, doctrine, and personnel in joint operations."[76]

3. Follow-on Research

The next several paragraphs discuss possible follow-on research for other thesis students to address. These are areas the authors believe may assist the UOC, CAC2S, and CoNDOR programs even further as this thesis work is completed.

First, throughout the testing evolutions of this research the authors implemented commercial off-the-shelf technologies into the established networks formulated by the authors. The data collected was mostly throughput data of file transfers, voice calls, and streaming video. This did not replicate actual data produced by a UOC, CAC2S, or CoNDOR scenario. During May 2002, CAC2S used an Optimized Network Engineering Tool (OPNET) to model the actual network traffic that would be generated during live operations. This model was using the MRC-142 and TRC-170 throughput capabilities between nodes and fiber runs in the intra-nodal setup. Further research could be done with OPNET to model and simulate the new wireless technologies recommended for each of the three programs. This would provide further examination of the benefits of these transformational wireless technologies for the Marine Corps.

This research project dealt mostly with point-to-point communications. Therefore, a single point of failure within the network architecture would cause degradation across the entire network. For example, in Field Test Four if connectivity through the tethered balloon was lost, the NOC would not have been able to

[76] Dennis L. Gette, Space and Naval Warfare Systems, Transformational Science and Technology; "Demonstrate a Prototype FORCEnet Engagement Package (FNEP) Combat Reach Capability (CRC)" (Jan 2004)

communicate with MRC #1 and MRC #2. If the NOC was employing some type of point-to-multipoint technology that connected to the POP and MRC #2, then redundant communications would have been established. Follow on research could focus on the point-to-multipoint technologies that this research was unable to address.

The above statements also yield to a good lead into another research area, which is mesh architecture. In mesh architecture, the communication devices in the network recognize each other. This leads to a self-healing, self-forming network when in each communication device can sense the other communication devices in its environment and is able to communicate within its surroundings. Once the communication device identifies its surroundings, then it can relay information via the mesh architecture to its neighboring devices. This type of technology is a truly network-centric environment that is required for the future.

Next, Broadband satellite was employed during Field Test Four. It provided stationary communications services, but the satellite dish mounted on the SUV was able to pull into a site and automatically track where the satellite antenna was located. If this type of service can be provided while on-the-move, units can keep an updated common operational picture even when displacing. Omega Systems, maker of the satellite dishes at Field Test Four, said they are working on these satellite capabilities for on-the-move communications. Follow on research could study the impact of using high throughput (Broadband satellite) capability while in motion and how it can effectively be implemented into the UOC, CAC2S, and CoNDOR.

Several technologies that provide transformational throughput were evaluated in this research. Most had no encryption built into them, the exception being Redline and Alvarion with their OFDM products. Further research is also warranted to identify if the technologies tested could have Type 1 encryption built into them. Since Type 1 encryption is currently in stand-alone devices, the researched being suggested is to imbed the encryption into the product. Since Harris did this with their SecNet-11 cards, the idea should be feasible, providing the proper agencies were involved. If so, this would alleviate having to insert two bulk encryption devices into either side of a link to encrypt and decrypt information.

Furthermore, the next topic of conducting a cost analysis of replacing legacy communications systems with the commercial off-the-shelf technologies could also be researched. While the cost of the product can be taken into consideration, the cost of encryption may be the biggest expense. A formula could be developed to determine what is more important to the Marine Corps -- cost or capability.

The technology that proved most impressive during the last two field tests was OFDM. To incorporate a technology in the Marine Corps architecture that can communicate over hills, through trees, and around building may save lives by eliminating the need for retransmission sites. This research did not evaluate OFDM while traversing over large mountains. A breaking point of where the technology is still useful would be another good follow on research topic. In addition, the use of OFDM was not evaluated over water. Since the technology breaks up a single carrier into multiple carriers, more detailed research could identify if water has any adverse effects on the usefulness of this technology. Finally, OFDM is unproven in aerial relays. The need to research whether the signal can be amplified in an aerial scenario would be beneficial. This would identify if the technology were better suited to employ aerial than 802.11b.

There is only one NSA certified Type 1 encryption device known that can encrypt classified traffic in a wireless LAN. This device is the Harris SecNet-11 card. Much research has been done with the product, but more extensive research needs to be done to identify how a SecNet-11 access point handles multiple users in a wireless LAN at the same time. This follow on research would identify how much traffic load an access point could handle, and how these access points need to be employed at different levels of command.

APPENDIX

A. FSONA

fSONA Communications is a provider of current and next generation FSO solutions. Their corporate headquarters is in Richmond, British Columbia, Canada. Founded in 1997 with a goal to develop optical transmission products for the broadband access market, fSONA created the SONAbeam™ family. The SONAbeam comes in three different series, M, S, and E. The M series has four transmitting lasers, the S series and E series have two. Each series offers different throughput capabilities that vary from 1.5 Mbps to 1.25 Gbps.[77] fSONA has also recently completed the development of an OC-48 prototype system, the SONAbeam 1250-M. The SONAbeam 155-M and SONAbeam 155-E were used during this thesis research.

Throughout the testing evolutions, we noticed many advantages of the SONAbeam 155-M. The SONAbeam 155-M puts out 640 milliwatts of power, which is the most of any company's product we worked with, and its four transmitting lasers help offset effects of scintillation. The SONAbeam 155-M advertises the longest distance at 5700 meters out of any FSO product, which was within the scope of our testing. The skin of the SONAbeam 155-M is made of cast aluminum, which is very durable material. Cast aluminum is designed to withstand rugged environments such as those encountered in the military. Finally, the lasers use the 1550 nanometer wavelength, which is suitable for the military due to laser designators being in the 700-850 nanometer range.

A couple of disadvantages to the SONAbeam 155-M were that it requires a very stable platform to be mounted on. Both heavy duty (200 pounds) and lightweight mounts (50 pounds) were used during the testing events. The SONAbeam 155-M is also a very heavy piece of equipment weighing nearly 44 pounds.

[77] http://www.fsona.com (April 2004).

The SONAbeam 155-M is made for an environment that is static such as that found at an Air Command Node (ACN) within the CAC2S architecture. It could also be used at MAGTF level headquarters to connect the COC with the communications site.

On the other hand, the SONAbeam 155-E is a very lightweight piece of equipment, which can be mounted on top of a telescopic stand. This allows the SONAbeam 155-E to be used with units that displace often.

For information on fSONA and their products, contact Mike Corcoran at 877-463-7662 (office) or 604-312-6176 (cell). His e-mail address is mcorcoran@fsona.com.

B. LIGHTPOINTE

Founded in 1998 by Heinz Willebrand, Ph.D., a research visionary in the field of physics and lasers. LightPointe's application-specific Flight™ Optical Wireless family combines the speed of fiber with the flexibility of wireless. Their products transmit voice, data, and video at bandwidths ranging from single T-1/E-1 up to 2.5 Gbps at distances up to 4 km, over any protocol. Over 2,000 of their products are installed in over 60 countries. Two of Lightpointe's partners include Cisco and Corning Cable Systems.[78]

The Flight product line includes the FlightLite, FlightSpectrum, and FlightStrata. During this research, the FlightStrata was used at connectivity speeds of 1.25 Gbps and 155 Mbps.

The unique aspect about the equipment used was the Fly Away kit that the link head and accessory equipment were packaged in. This consisted of a case that was about 5x2x2 feet. A complete link would consist of having two cases, each weighing about 70 pounds. The link was the easiest to establish out of all companies involved in this research project. From start to finish, a link was established within 15 minutes with two inexperienced personnel setting up the equipment. The stand was very lightweight that the link head was placed on.

[78] http://www.lightpointe.com/index.cfm/fuseaction/corporate.aboutus (April 2004).

Alignment of the lasers is fairly straightforward; the scope that is used to initially align the lasers is mounted within the link head and then LED bars light up on the back of the link head to signify the strength of the signal. Lightpointe chose to utilize the 750-850 nanometer range for their lasers, but they have stated that they could operate in the 1550 nanometer range if the demand was established.

Lightpointe's Fly Away kit is ready for deployment right now, and it is definitely packaged the best out of all FSO companies. However, the skin of the link head would have to be ruggedized to withstand harsh environments. Their products could be used at any level in the UOC or CAC2S architectures. It also could be an option in the CONDOR setup at the company level talking to the POP vehicle.

For information on Lightpointe and their products, contact Jim McGowan at 858-643-5216 (office) or 858-232-4873 (cell). His e-mail address is jmcgowan@lightpointe.com.

C. MRV

Founded in 1988, MRV Communications, Inc. is a public company. With 1,500 employees, MRV maintains eight R&D and manufacturing centers in the U.S., Europe, Israel, and the Far East and 50 customer service, support and sales offices in 22 countries. MRV FSO products sold to the Federal markets are U.S.A. manufactured. MRV is the Worldwide leader of FSO with more than 6,000 FSO links and have 19 FSO patents. MRV has over 20 years of R&D in FSO technology, and they were originally funded by DARPA to further develop the FSO technology. Their R&D included a 2,000 kilometer FSO link to a satellite supporting tracking. MRV has DoD installations of their FSO products including the Army and Air Force. Furthermore, MRV has four different product lines that they manufacture: Advanced Terminal Servers secure IT solutions for remote control/access, media converters, Terescope Optical Wireless (FSO), and Optical switches, routers, and modems.[79] The Terescope 3000 was used during the testing evolutions, along with the FSO-RF automatic switch, OptiSwitch.

[79] http://www.mrv.com/corporate (April 2004)

Many advantages are found with MRV and their products. First, the company has been around for a long time and they have a diversity of products, so they do not rely solely on FSO for revenue. For these reasons, they are a company to depend on for the long term. The Terescope 3000 was set on a lightweight telescopic stand and it was relatively easy to setup. It had a camera alignment tool so one could see the laser light from the opposite end on the viewing screen. This allowed for the link head to be easily maneuvered into the cross-hairs on the screen for alignment. The OptiSwitch was quite impressive. When FSO and RF links are attached using the MRV patent Terescope Fusion, the Terescope Fusion automatically goes to the strongest link. Thus, if fog rolls in and the FSO link loses signal to the other side, then the RF takes over. This is all transparent to the user as there was no time delay or break in transferring files. For MRV's media converters, the latest technology allows one to pick and choose what "pluggable" optical transceivers and/or electrical interfaces they want to use. These Small Form Factor Pluggables (SFPs) are also going to be engineered into future MRV FSO products which will allow the end user to always have the right interface to connect to the network equipment. The customer will not have to consider which scope head to purchase for single-mode or multi-mode fiber or worry about media converters. This will be built into the head of the scope.

MRV's Terescope products and accessories are suitable for any level of command in the UOC, CAC2S, and CONDOR communications architectures.

For information on MRV Communications and their products, contact Tim Kcehowski at 724-934-5991 (office) or 412-596-1729 (cell). His e-mail address is tkcehowski@mrv.com.

D. TERABEAM

Terabeam was founded in 1997 and its headquarters is in Redmond, WA. They produce FSO products along with 60 GHz millimeter wave (MMW) systems.[80] The Elliptica, FSO product, was used during our testing events, and the MMW system was demonstrated.

80 http://www.terabeam.com/home.shtml (April 2004).

Terabeam uses only one laser compared to other companies that use multiple lasers. To paraphrase Carrie Cornish on February 4, 2004 at Raytheon in San Diego, CA, "…Terabeam uses a higher quality single laser, because over distance multiple lasers end up overlapping which provides no more of a benefit than the single laser…" The one laser does use the 1550 nanometer wavelength, a more favorable wavelength for use in military operations.

The features that make Terabeam's Elliptica stand out are the quality of their lab procedures in developing the product, significant auto-tracking feature that compensates for movement, ease of setup and teardown, minimal amount of small parts to lose over time, and the camera feature to align the links.

After visiting Terabeam's lab one could see the impressive procedures set in place to ensure the product is fully developed and tested before going to the customer. The auto-tracking feature is also unique. It can compensate for movement of buildings, accidental movement of the stand, and for the stand settling into the ground. Products that can be set up and torn down in an expedient manner are looked at favorably in the military environment. It is also important to develop systems with a minimal amount of small parts. Over time, small parts will definitely get lost in the military environment. The Elliptica was simple to set up, easy to use, and free of clutter and small parts. The camera feature for the alignment assists in establishing a link very quickly. After hooking up a laptop to the Elliptica, all the user has to do is look at the picture that the camera from the linkhead is providing and move the link head appropriately to line up with the other side.

As the Elliptica is a very suitable alternative to the UOC, CAC2S, and CONDOR communications architectures, the skin of the Elliptica would have to be hardened for the constant wear and tear it would undergo in the field.

For information on Terabeam and their products, contact Jim Olson at 610-408-9380 (office) or 206-604-7429 (cell). His e-mail address is jim.olson@terabeam.com.

E. ENSEMBLE

Ensemble was founded in 1997 and its headquarters is in San Diego, CA. Their wireless broadband system (Fiberless) includes radio transmission base stations and antennas, multiplexers, and network management software capable of providing both Internet connections and voice services. Ensemble Communications designs, manufactures, and markets point-to-multipoint wireless system for Local Multipoint Distribution Services (LMDS).[81] They also offer network design, product integration, and project management services.[82] The 16200 Hub Station, the 320 Multiplexer, and the Fiberless 282 Series Outdoor Mounted Unit (ODU) were used for the experiments.

Alignment of the antennas was straightforward; the authors pointed the antennas in the direction of each other. Once there was connectivity between the two antennas, the 320 Multiplexer and the 16200 Hub Station would illuminate a connectivity light on each component respectively. The unique quality of their wireless broadband system was the three major components took little effort to set up. From start to finish, antenna alignment was established within 15 minutes with two inexperienced personnel setting up the equipment. In addition to the ease of antenna set up, Ensemble Communications took advantage of the available bandwidth by carrying the largest packet payload of any point-to-multipoint system.[83] The largest packet payload is accomplished by Ensemble Communications' Adaptix technology. Ensemble Communications' Adaptix technology consisted of combining Adaptive Time Division Duplexing, Adaptive Time Division Multiple Access, and Adaptive Modulation. This patent maximizes the spectrum by taking advantage of the entire waveform.

One disadvantage that Ensemble Communications faced during testing events was that equipment was an ATM based system. The configuration for the routers was extremely difficult and extremely time consuming. In one particular case, the router and network configuration took up to eight hours before any testing was able to take place.

Ensemble Communications was closed in April 2004.

---

81 http://www.ensemble.com (May 2004)

82 http://www.hoovers.com/ensemble-communications/--ID__104236--/free-co-factsheet.xhtml (May 2004)

83 http://www.ensemble.com (May 2004)

F. ALVARION

Founded in 1992, Alvarion was solely focused on broadband. Alvarion is a world provider for Point-to-Multipoint (PMP) Broadband Wireless Access (BWA). Alvarion supplies integrated solutions to telecom carriers in order to assist telecom carriers in providing sustainable voice and data connectivity in the broadband market. The broadband market covers residential area, SOHO (small office, home office), markets through small and medium enterprises, and multi-tenant units/ multi-dwelling units. Alvarion introduced its BreezeACCESS VL system. The BreezeACCESS VL system is a PMP wireless broadband system which operates between the 5.725 to 5.850 Ghz frequency band. This system uses OFDM technology in order to maximize performance when the distant end is not line of sight. Some equipment characteristics include: an OFDM system, Adaptive modulation (BPSK, QPSK, 16 QAM, 64 QAM), a channel bandwidth of 20 Mhz, enhanced security, automatic transmit power control, and offers over-the-air software upgrade and configuration upload/download.[84]

The BreezeACCESS VL demonstrated a quick and easy set up. The outdoor unit, which consists of antennas and a radio, was erected on a lightweight retractable pole, which was secured by parking a vehicle over the base plate of the pole. Once the outdoor unit was secured and aligned, the indoor unit was connected to the network's router.

The issue that Alvarion encountered was the alignment of the antennas. On the underside of the antenna, there is a module that indicates signal strength level, which is not visible when adjusting the antenna. This small dilemma could be resolved through the use of either moving the module to where it can be seen when adjusting the antenna or by replacing the module with some sort of audio indicator that notifies the technician the antenna is aligning properly.

For information on Alvarion and their products, contact Jasper Bruinzeel at 760-517-3149 (office) or 760-685-2015 (cell). His email address is jasper.bruinzeel@alvarion.com.

[84] http://www.alvarion-usa.com/RunTime/Materials/PDFFiles/alv_BA%20VL_pg.pdf (May 2004)

G. REDLINE

Founded in 1999, Redline Communications Inc. is headquartered in Markham, Ontario, Canada. Redline Communications is an innovative provider of second-generation broadband fixed wireless systems.[85] Redline's products are based on an advanced form of OFDM technology. This technology interlocks three different techniques which include the OFDM data engine; an increased efficiency of the medium access control layer and the radio frequency; and multipath distortion effects and interference.

Redline Communications introduced the AN-50 OFDM system with sector and omni-directional antennas. The AN-50 system operates in the license-exempt 5.8 GHz band and includes advanced technologies to address potential inter-cell interference issues. The AN-50 maximizes spectral efficiency with a unique patented bi-directional adaptive modulation technique, automatically selecting any of eight modulation schemes providing a solid connection even in challenging link conditions. In addition, the AN-50 delivers an over-the-air rate of up to 72 Mbps, a robust non-line-of-sight (NLOS) capability, and audible antenna alignment and diagnostic capabilities.[86]

Redline Communications equipment was very easy to set up. The alignment of the antenna was augmented by an audio signal that assisted the technician in the alignment. This feature proved to be extremely helpful in the set up / tear down process of the system. The OFDM technology demonstrated to be a BLOS technology up to 20 km (depending on the antenna used).

The only issue that Redline encountered during the testing evolution was that their switch could only be set to auto negotiate. In order to maximize throughput across the link, the test bed was designed around the network routers to be configured at speed 100 Mbps with full duplex. The miss-matched configuration degraded the link across the network and limited the maximum throughput the equipment was capable of producing.

---

[85] http://www.redlinecommunications.com (May 2004)

[86] Redline Communications, "Redline Family White Paper", October 2003.

For more information on Redline Communications and their product, contact Dave Rumore at (905) 479-8344 (office) or (561) 254-0758 (cell). His email is drumore@redlinecommunications.com.

H. SEGOVIA (BROADBAND SATELLITE)

Segovia was founded in 2002 and is headquartered in Herndon, Virginia. Segovia provides omnipresent Global IP networks and services. The IP coverage that is provided by Segovia covers virtually a unified global network. During the testing evolution, Segovia was teamed up with Omega Systems, a company who produces the satellite dishes. Segovia's throughput can range from 128 kbps to 9 Mbps. Segovia's Internet service features no limit on monthly usage, high performance with low cost, Type-1 encryption compliant, and a fully managed solution. Segovia's IP Voice features high quality voice, full range of PBX features, and reduced costs. In addition, Segovia offers a VPN feature, which includes easy IP administration, security, use of the Internet, and completely private network.[87]

Segovia's customer service and teamwork left a customer oriented impression on these authors. Senior Sales Engineer, Ross Warren, went above and beyond expectations in order to assist in making Field Test Four a success. His coordination with his headquarters arranging for the airborne satellite to act as a retransmission site for the link between the two testing sites was key. In addition to providing customer support for his equipment, he also assisted the students with the configuration of the entire network of routers, switches, access points, and IP phones.

For more information on Segovia or Segovia's services, contact Jeff Howard at (703) 621-6450. His email is jeff.howard@segoviaIP.com.

I. OMEGA SYSTEMS, INC.

Omega Systems, Inc. was founded in 1998 and is headquartered in Colorado Springs, Colorado. Omega Systems was the company that provided the satellite antennas for Field Test Four. Omega Systems is not only a satellite antenna company. They also

[87] http://www.segoviaip.com/ (May 2004)

develop requirements-based solutions derived from a thorough analysis of the customer's internal process and external communications needs.[88] Omega Systems provides the following products and services: Business Process Analysis and Re-engineering, Requirements Analysis, Network Engineering, Application Engineering, System Analysis and Integration, C4ISR Architecture Analysis, Internet Business Solutions, and IT Equipment Sales and Services.[89]

Marine Corps specific projects that Omega Systems Inc. has supported with onsite support are: C2 Operational Architecture for Marine Corps Combat Development Command (MCCDC); Network Design, Installation, and Management for Marine Corps Institute; Warfighting Functional Analysis for MCCDC; USMC Online Correspondence Course System for Marine Corps Institute; LHA-R Operational Architecture for MCCDC and SPAWAR, and Single Integrated Operational Picture for MCCDC.[90]

Omega Systems, Inc introduced two one-meter satellite terminals during the field testing evolution. One terminal was a ground terminal that was utilized at the Mobile Research Facility; the other was mounted on a Sports Utility Vehicle and was located at the remote site. The ground terminal was a multiple case system that was powered by a 110V source, and its transmitting frequency was between 13.75 – 14.50 GHz with a receiving frequency between 11.70 – 12.75 GHz. The satellite dish was manually pointed at the satellite for connectivity. The mounted terminal required the same power load and it operated in the same frequency band. However, it automatically aligned itself to the satellite once it was turned on. This yields for a quick setup time and operation of the equipment can begin within minutes.

For more information on Omega Systems, Inc. contact Matt Jones at (719) 886-2212 (office) or (719) 337-1588 (cell). His email address is mjones@omegasys.net.

---

[88] http://www.omegasys.net/documents/corporatecs.pdf (May 2004)

[89] www.omegasys.net (May 2004)

[90] Matt Jones, VP Business Development, "Past Performance Addendum, Omega Systems Inc." (May 2004)

J. NERA (INMARSAT)

Nera ASA, based in Norway, was established in 1947, and it is one of the world's leading companies in the field of wireless telecommunications using microwave and satellite technology. The company has offices in 26 countries and more than 1,500 employees around the world. Separate companies for product development and sales are located in Boston, MA and Dallas, TX.[91] Nera's NWC Voyager system, INMARSAT capabilities on-the-move, was looked at closely during the March testing event. Marine Corps Systems Command is also looking at Nera for possible mobile communications for the CONDOR architecture. Finally, the World Communicator was also demonstrated but not used during the course of research in these testing evolutions.

NWC Voyager is a vehicular Global Area Network (GAN) satellite terminal operating over INMARSAT I-3 in spot-beam, prepared for I-4. The GAN capability combines the high quality and speed of the full mobile ISDN 64 kbps service with the flexibility of Mobile Packet Data Services (MPDS).[92]

As discrete and convenient as hand luggage, the Nera WorldCommunicator enables one to access the internet and send and receive e-mail, data files, fax and voice messages from one compact unit anywhere in the world. By linking two units together the throughput is doubled to 128 kbps.[93]

During the testing, the NWC Voyager was easily mounted on a solid platform made of wood in the back of a pickup truck. While the vehicle was in motion, phone calls and file downloads were performed without error. There were some issues, however, when the look angle of the Voyager was blocked by hills next to the vehicle the download was unsuccessful. In addition, integrating the Voyager system into the established network was not accomplished during the testing event.

Nera's products are definite players in the military, mobile communications realm. Communicating on the move has emerged as a requirement to keep commanders informed at all times.

---

91 http://www.nera.no/index.html (April 2004).

92 http://www.nera.no/5243067FA7B57D0BC1256E510054623A.html (April 2004).

93 http://www.nera.no/844AED60C2F14035C1256A300054A93D.html (April 2004).

For information on Nera and their products, contact Peter Coffman at 713-294-4543 (cell). His e-mail address is pc@nera-sp.com.

K. IMUX (IRIDIUM)

General Dynamics' Reachback Iridium Inverse Multiplexer (IMUX) combined four 2.4 Kbps Iridium channels to increase the overall bandwidth to 9.6 Kbps.[94] The IMUX utilized the channels by separating the input information and sending the parsed information across the four different channels. Another Reachback unit recombines the original information by using buffers in order to compensate for variations in link delays produced from the four satellite channels.[95] The four L-band channels were wired into the IMUX box that provided three modes of operation; data, video, and voice transmission. The data mode ensured data was not altered during transmission (data files, critical imagery, etc.). The video transmission mode did real-time video transmission using custom video compression software (used when loss of video quality can be tolerated). The voice mode was a satellite telephone.

The Reachback can be implemented in a variety of combinations to include mobile-to-mobile, mobile-to-network, and mobile-to-Public Switched Telephone Network (PSTN). The mobile-to-mobile configuration allows two Reachback units to communicate with each other. The mobile-to-network allows a mobile Reachback unit to communicate back to a central server. The mobile-to-PSTN configuration allows a mobile Reachback unit to communicate to four standard PSTN phone lines.

During the testing, the product performed as expected. The IMUX is definitely a current solution option for BLOS. Although the throughput is limited, the product does offer configurations that augment more data throughput on the tactical battlefield.

For more information on the IMUX, contact Don Lesmeister at (480) 441-0340 (office) or (480) 518-2208 (cell). His email address is Donald.Lesmeister@gdds.com.

94 http://www.gdds.com/satelliteservices/ (May 2004)

95 www.gdds.com, white paper, "Reachbak Iridium Inverse Mulitplexer for Over-the-Horizon Worldwide Transmission of Voice, Video, and Data" (May 2004)

L. GENERAL DYNAMICS (RFM)

The Radio Frequency Module is a product produced by Ceragon Networks; however, the product is packaged by General Dynamics Decision Systems (GDDS). GDDS packages the product in appropriate cases along with a Cisco 2950 switch for their customers. This case along with the microwave dish is field expedient and hardened to withstand a rugged military environment. The antenna sits on top of a lightweight telescopic stand, which is separate from the case. A distance of 9 kilometers can be reached with the one-foot antenna, which was used during the testing event, and 13.5 kilometers with the two-foot antenna.[96] RFM is a point-to-point, line-of-sight, OC-3 capable (155 Mbps) microwave product.

According to a General Dynamics data sheet, "RFM v3 contains a baseband assembly with power supply, an Ethernet switch, and a dual DS1 to fiber optic modem that is operated and maintained inside the transit case located inside user provided facilities. It also contains an RF assembly and antenna that are installed and operated outside the user provided facilities up to 200 feet away."[97] This self-contained system demonstrated a consolidated system that provided high 80's Mbps throughput of data.

During the testing, the product was very impressive. The RFM could be implemented now in the Marine Corps for intra-nodal and inter-nodal connectivity.

For more information on the RFM, contact Jon Seime at (480) 441-2983 (office) or (480) 510-4126 (cell). His email address is jon.seime@gdds.com.

M. KG-235 INE

GDDS is the manufacturer of the KG-235 Sectéra In-Line Network Encryptor (INE). The KG-235 is specifically designed to support IP/Ethernet operating over standard commercial networks that require U.S. Government Type 1 security, but it is also used in the military environment. The INE protects all levels of data, from Government Classified to TS/SCI. It provides confidentiality, data integrity, peer identification, authentication and mandatory/discretionary access control services. The

[96] GDDS, "Radio Frequency Module (RFM) v3 Handout", 2003.

[97] GDDS, "Radio Frequency Module (RFM) v3 Data Sheet", 2003

INE is software configurable, it utilizes the new Sectéra INE Configuration Manager, and it is keyed using material supplied by the U.S. Government's Electronic Key Management System (EKMS) for Type 1 products.[98] The interfaces on the INE are two RJ-45 10/100 Base-T and two DB-9 Serial Ports. The INE can support up to 17 Mbps of aggregate data throughput.[99] With further upgrades, the INE will be able to support up to 60 Mbps.[100]

During the testing, the product did not perform as expected. The INE needed the latest firmware in order to maximize a greater throughput and the authors were expecting a higher throughput result from the product. When the INE was tested at Raytheon, the INE had an older version of firmware installed. The INE specifications rate the product up to 17 Mbps aggregate data throughput.[101] The maximum throughput observed for the INE was around 5 Mbps.

For more information on the INE, contact Don Lesmeister at (480) 441-0340 (office) or (480) 518-2208 (cell). His email address is Donald.Lesmeister@gdds.com.

N. SECNET-11

SecNet-11 is a Harris product. Harris Corporation is an international communications equipment company focused on providing product, system, and service solutions for commercial and government customers.[102] The company is headquartered in Palm Bay, Florida. Providing service worldwide, Harris has sales and service facilities in more than 90 countries.[103]

SecNet-11 is a tool for a secure 802.11b wireless local area network. The SecNet-11 product family offers a scalable, mobile, quick to deploy solution for a military environment. The SecNet-11 family includes products like the SecNet-11 Plus PC card,

---

98 http://www.gdc4s.com/Products/sectera.htm (April 2004).

99 http://www.gd-decisionsystems.com/sectera/ine/upgrade/C4SSectera_INE_PIB_V2_12-5-03.pdf (May 2004)

100 Donald Lesmeister, GDDS sales engineer, phone conversation (February 2004)

101 http://www.gdc4s.com/Products/secteraspecs.htm

102 http://www.harris.com/ (May 2004)

103 www.harris.com (May 2004)

the SecNet-11 PC card, the SecNet-11 Wireless Bridge, the SecNet-11 Access Point, and the SecNet-11 Key Fill Cable. Based on the IEEE 802.11b standards, the SecNet-11 Plus PC card has been certified as part of the National Security Agency's (NSA) Commercial COMSEC Evaluation Program (CCEP).[104]

As discussed in the thesis, SecNet-11 operated as expected. SecNet-11 is a secure National Security Agency (NSA) Type 1 and FIPS-140 compliant encryption device. Therefore, classified information up to Secret can be passed across a SecNet-11 network.

For more information on SecNet-11 and its family of products, contact Mark Slepikas at (321) 727-5141 (office) or (321) 917-7019 (cell). His email address is mslepika@harris.com.

O. JTRS

According to Harris, "The Joint Tactical Radio System (JTRS) is a U.S. military initiative to develop a family of software programmable and modular communications systems that will become the principal means of communications for warfighters in the digital battlefield environment. All waveforms, protocols, encryption, and communications processes will be implemented in Software Defined Radio (SDR) technology. JTRS is a family of affordable, high capacity, software programmable tactical radios providing interoperability for line of sight, and beyond line of sight in a wireless mobile network. JTRS is identified in five clusters; cluster 1 will consist of ground vehicular, rotary wing, and TACP; cluster 2 will consist of handheld devices; cluster 3 will consist of Maritime and fixed sites; cluster 4 will consist of fixed-wing (Airborne); and cluster 5 will consist of embedded devices."[105] According to LtCol Wilson, "…through the addition of WNW, the JTRS will significantly improve tactical networking on the battlefield."[106]

Testing was not conducted due to the infancy of the system. Therefore, JTRS is briefly discussed in the conclusions of this thesis. For further information on JTRS and

104 http://govcomm.harris/secure-comm/ (May 2004)

105 http://www.rfcomm.harris.com/jtrs.html (May 2004).

106 Jefferey D. Wilson, Lieutenant Colonel, United States Marine Corps, "Introducing the Joint Tactical Radio" (Marine Corps Gazette, Aug 2002)

its clusters, contact Captain Andrew G. Chapman, United States Marine Corps, at (703) 432-4360. His e-mail address is ChapmanAG@mcsc.usmc.mil.

P. ATM

As mentioned earlier, Ensemble operated off an Asynchronous Transfer Mode (ATM) network. The ATM was developed because there was a need for delivering services (video, voice, and data) at high rates of speed across a network of computers. Networks of the past consisted of a network of telephone systems, Integrated Services Digital Network (ISDN). The technology ATM replaced was circuit switched Time Division Multiplexing (TDM). The nice feature ATM offered was that ATM provided more bandwidth to be available across the network when compared to TDM. Most carriers of Internet Protocol (IP) services have maintained for years an ATM layer over which IP traffic travels. This was due to the reliable, scalable, higher availability, and Virtual Private Network features that lie within ATM and lack in traditional IP, such as the lack of flow control and sequencing. IP technology today does not lack flow control or sequencing.

The manner in which ATM worked with data has changed drastically over the past decade. ATM in the past had a major shortfall in data environments due to "cell-tax", meaning there was significant overhead in packet-oriented networks. For instance, if a piece of data was sub-divided into ATM's short fixed length packets of 53 bytes and several packets were full except one which only had a few bytes in it, then ATM's overhead would fill that packet and send it across the network. This was not the most practical of solutions, so adoption of the Frame-based ATM over Synchronous Optical Network (SONET)/Synchronous Digital Transport took place. ATM still continued to add value to IP-based services through means like SONET. ATM would also simultaneously offer other non-IP applications and services to reside on the same core infrastructure. However, according to Comer, "ATM has not been widely accepted.

Although some phone companies still use it in their backbone networks, the expense, complexity and lack of interoperability with other technologies have prevented ATM from becoming more prevalent."[107]

Q. LINKSYS (802.11A/802.11B)

Linksys is a company that merged with Cisco. The authors used several access points made by Linksys. In particular the WAP55AG was used in access point configuration. The WAP55AG is a Linksys Dual-Band Wireless A+G Access Point. The product contains two separate radio transceivers in order to support three wireless specifications. The first transceiver, 2.4 GHz frequency band, supports the 802.11b standard and the 802.11g standard. The second transceiver, 5.4 GHz frequency band, supports the 802.11a standard.

The product was fairly difficult to configure in the beginning. Towards the end of the experiments the configuration of the product was straightforward because of the experience. This product would be a good fit within an unclassified military network.

The WAP11 was another Linksys product that was tested by these authors. The WAP11 uses 802.11b standard for its technology. The WAP11 was used in a bridge mode configuration to tie two networks together. The WAP11 was also used in an aerial relay configuration. Initially, the WAP11 was fairly difficult to configure. The WAP11 was straightforward to configure at the end of all of the testing evolutions. Similar to the WAP55AG, this product can be used in an unclassified environment in the military.

For more information on the Linksys or the Linksys products, contact George Delisle at 703-484-5733 (office) or 703-217-7599 (cell). His e-mail address is gdelisle@cisco.com.

R. CISCO

Cisco was founded in 1984 by a small group of computer scientists from Stanford University. It now has over 34,000 employees and is based in San Jose, CA. Cisco was

[107] Douglas Comer, "Computer Networks and Internets with Internet Applications", (Prentice-Hall Inc, New Jersey 2001, third edition), pg. 229

founded on a culture based on the principles of open communication, empowerment, trust, integrity, and giving back to the community[108], and the authors witnessed these same values in their dealings with Cisco. In December 2003, the authors approached a Cisco Account Manager in the District of Columbia area, George Delisle, who works closely with the Marine Corps. A request was granted by Mr. Delisle to supply the authors with two Cisco 3745 Multiservice Access Routers, two Cisco IP Phone 7960Gs, one CallManager Server, two Cisco 350 Aironet Bridges, one ATM interface card, and four Gigabit Interface Converters (GBIC) to be utilized during their testing exercises.

Key features for the Cisco 3745 are as follows: two integrated 10/100 LAN ports, two integrated Advanced Integration Modules (AIM) slots, three integrated WAN Interface Card (WIC) slots, four Network Module (NM) slots, two High Density Service Module (HDSM) slots, 32MB Compact Flash, 128MB DRAM, and support for all major WAN protocols and media.[109]

The Cisco IP Phone 7960G offers four dynamic soft keys that guide a user through call features and functions. Built-in headset port and integrated Ethernet Switch are standard with the Cisco IP Phone 7960G. It also includes audio controls for full duplex speakerphone, handset and headset. The Cisco IP Phone 7960G also features a large, pixel-based LCD display.[110]

The Cisco Call Manager Server that was used was the MCS-7825H-2.2 EVV1 model. Next, the Cisco 350 Aironet Bridges were not used during the testing events. An ATM interface card provided a single-mode intermediate-reach (SMI) fiber uplink port with enhanced performance. This was used with Ensemble's equipment. Finally, the GBIC accepted a multimode fiber at a wavelength of 850 nanometers, and the port took a SC-type connector. The GBIC was successfully used with Lightpointe's fiber cable from their link head.

---

108 http://newsroom.cisco.com/dlls/company_overview.html (April 2004).

109 http://www.cisco.com/en/US/products/hw/routers/ps282/ps284/index.html (April 2004).

110 http://www.cisco.com/en/US/products/hw/phones/ps379/products_data_sheet09186a0080091984.html (April 2004)

For information on Cisco's support, contact George Delisle at 703-484-5733 (office) or 703-217-7599 (cell). His e-mail address is gdelisle@cisco.com.

S. SPIRENT (SMARTBITS)

For decades, the world's leading communications companies have used Spirent solutions to conduct performance analysis tests in labs on the latest technologies. As new communications services are introduced in the market, Spirent provides the tools to offer service assurance and field test for improving troubleshooting and quality. Spirent Communications has 1,800 employees in 14 countries, and its headquarters is in Rockville, MD.[111]

During the Raytheon testing, Spirent allowed the authors to utilize their Smartbits product to analyze the network and technologies being evaluated. The following is a list of the Smartbits products that were utilized during testing: SMB-600 Chassis, LAN 3101B 6-port 10/100 Ethernet interface, SWF-1208A SmartVoIPQoS, and ACC-1040A Nanosync GPS Interface Kit. A separate company, Zyfer, provided the GPS receivers and antennas.

The GPS receivers and antennas were used to synchronize the two chassis on separate ends. Unfortunately, the network at Raytheon headquarters was positioned too close to the building, so the look angle of the GPS antenna could not see the satellite. Thus, the two chassis could not provide any latency data, but they were able to provide throughput tests.

Through the Smartbits packet generator, each technology was stressed to its fullest allowing one to see the exact throughput of the link. This was mostly done with voice and data traffic in a full duplex setup. At times, voice and data were done separately. For the most part, eight voice calls were replicated both ways, and data was sent in increments of 10 Mb starting at 10 and ending at 100 Mb. Overall, this setup allowed one to see what amount of frame loss was being experienced as traffic got heavier and heavier. As the frame loss become closer to 100 percent, a determination could be made on the exact throughput for the established link.

[111] http://www.spirentcom.com/about/index.cfm?wt=1 (April 2004).

For information on Spirent Communications and their products, contact Jeff Blanchard at 408-752-7159 (office) or 408-464-8948 (cell). His e-mail address is jeff.blanchard@spirentcom.com.

T. ZYFER (GPS)

Originally named Odetics Telecom, Zyfer was established in the mid-'80s, and incorporated as Zyfer Inc. in 1999. FEI-Zyfer's parent company, Frequency Electronics Inc. (FEI), was founded in 1961 and quickly gained world prominence in the Precision Quartz Crystal Oscillator Technology. FEI-Zyfer designs and manufactures GPS-aided precision time and frequency generation and synchronization products for commercial and government users. It is based out of Anaheim, CA.[112]

During this thesis research at Raytheon, the Nanosync II was used to provide synchronization to both of Spirent's chassis. This would allow for the VoIP QoS software to show accurate latency data. Unfortunately, one of the GPS receivers was positioned too close to a building, so it could not pick up enough satellites to provide proper signal. This location could not be moved. Thus, both chassis could not sync up and the latency data ended up being skewed. The Nanosync II was very lightweight and easy to use. It does take a special cable between the receiver and the antenna cable to be utilized.

For information on FEI-Zyfer and their products, contact Lee Chenoweth at 949-713-9801 (office) or 949-433-2800 (cell). His e-mail address is lee@timingtechnologies.com.

U. SOLARWINDS

SolarWinds.Net, Inc. was founded in 1995 and is headquartered in Tulsa, Oklahoma. SolarWinds develops and markets an array of network management, network monitoring, and network discovery tools. SolarWinds is organized in three divisions; Network Toolset Division, the Orion Division, and the Broadband Division. The division that enhances and releases new network tools is the Network Toolset Division. The

[112] http://www.zyfer.com/aboutus.html (April 2004).

division that works on server based solutions providing a complete web view of the network is the Orion Division. Finally, the division that develops solutions for high-speed data networks is the Broadband Division.[113] According to SolarWinds, their mission is "to provide Network Engineers and Consultants with a single comprehensive tool-set to reactively and proactively analyze, monitor and isolate networking issues."[114]

As mentioned in the thesis, SolarWinds was used to monitor the throughput in the network. Through the use of Simple Network Management Protocol (SNMP) with IP Network Browser and Internet Control Message Protocol (ICMP) the students were able to monitor the bandwidth utilization of a remote component on the network, the load on a Cisco router, or identify what devices were on a subnet. Additional detailed information it returned included details of each interface, port speed, IP Addresses, routers, ARP tables, and much more.

During the testing periods, the students ensured the devices on the network were SNMP enabled prior to conducting any tests. SolarWinds measured CPU load and the Cisco routers load. The gauge used SNMP to communicate with the device and displayed the results on the computer screen (Figure 80).

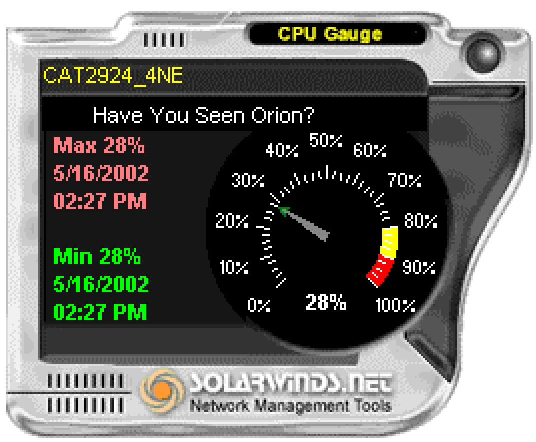

Figure 81. SOLARWINDS CPU GAUGE

The maximum throughput number was recorded onto a spreadsheet as the maximum throughput between two sites.

113 http://www.solarwinds.net (May 2004)

114 http://www.solarwinds.net/company (May 2004)

For more information, contact Sales Department (918) 307-8100 or www.solarwinds.net.

V. IPERF

Iperf was a tool used to measure Transfer Control Protocol (TCP, a protocol developed for the Internet to get data from one network device to another) bandwidth, allowing the tuning of various parameters and User Datagram Protocol (UDP) characteristics. Iperf reports bandwidth, delay jitter, and datagram loss. The program can be downloaded for free from the Internet. The authors used Iperf version 1.1.1, which was released in February 2000 for all the testing found in this thesis. There were a couple of ways to execute the program. One way was to run the batch file on the sending side while simultaneously running the batch file on the receiver's side. The second option was to go into the DOS prompt and type in the following commands once the user was in the Iperf folder, the sender would type "IPERF –c" (IP address packets are going to) "–w 8K 5 20" and the receiver would type "IPERF –s –w 64K". The meanings of the letters above are as follows: -c means to run Iperf in client mode; -w determines the TCP window size (sets the socket buffer sizes to the specified value, in the example above the window size is 8K. For TCP, this sets the TCP window size.); 5 is the transmit time of bytes; 20 is the time interval of transmission; -s means to run Iperf in client mode, connecting to an Iperf address that is running the host; -w is the window size for the receiving side, in this case, the size of the window is 64K.

Currently, there is an Iperf version 1.7.0 that can be downloaded from the Internet. If interested in more information on Iperf, go to http://dast.nlanr.net/.

W. VOIP

Voice over Intenet Protocol (VoIP) defines a way to carry voice calls over an IP network including the digitization and packetization of the voice streams. IP Telephony utilizes the VoIP standards to create a telephony system where higher-level features such as advanced call routing, voice mail, contact centers, etc., can be utilized.[115]

---

[115] http://www.cisco.com/en/US/tech/tk652/tk701/tech_protocol_family_home.html (April 2004).

Cisco 7960G IP telephones were used to provide voice service to the Local Area Networks (LAN). The phones took a simple CAT-5 cable connection, and the other end was connected to the LAN switch. The Call Manager server was always located with the Mobile Research Facility (MRF). The phones throughout the Wide Area Network would first talk to the server before making a call to another phone within the network. The server was connected to the MRF switch via CAT-5 cable. Each phone and server was assigned its own unique IP address.

From the testing, whenever SolarWinds measured a significant packet loss of greater than 10% in the links established between LANs, VoIP calls would drop. The exception to this was using OFDM. Since this technology splits its bandwidth into multiple channels, as long as one channel is getting across it will keep the call up. For example, when SolarWinds showed the link was down, greater than 50% packet loss, the VoIP call was still active. Finally, the network routers were all set to have voice as the number one priority.

For further information on the VoIP testing data, reference LT Manny Cordero's thesis research. This can be found through the NPS library at http://library.nps.navy.mil/home.

X. MLB (UAV)

Since 1988, MLB has defined the state of the art in small aerial platforms that include the tiny Trochoid micro UAV, the large Volcano, and the workhorse Bat. MLB is a small company with their business office located in Mountain View, CA. They were contracted to support the March testing with their Volcano UAV. The Volcano aircraft is designed to carry a 15 lb payload and up to an altitude of 12000 ft.[116]

During the March testing, the Volcano was utilized as a communications relay. A small wooden platform was strapped to the bottom of the plane with an omni-directional antenna, access point, DC to AC power converter, and one lithium battery used as the power source. The aircraft flew for about 3 hours a day for a three-day period. It was flying at altitudes from 400 to 1,000 feet. There was an onboard camera that could be

116 http://www.spyplanes.com/company.html (April 2004).

viewed from the base station where the aircraft was being controlled. Thus, the Volcano could double in its mission by doing aerial reconnaissance and communications relay simultaneously.

The aircraft was launched from the airfield runway, which it required about 500 feet of, with a handheld remote-control device. Once it was airborne, the computer program designed for the Volcano automatically controlled the UAV in accordance with the inputted track data. This program was able to save the track information from the entire flight, so one could tell where the aircraft had flown during its mission.

Communications on the ground to the UAV were very challenging mostly due to the antenna setup. Omni-directional antennas of 5 dBi gain with 1-Watt amplifiers were used on the ground and in the air. It was believed that the reason communication proved so difficult was the antenna on the UAV was pointing down from the bottom of the aircraft. Thus, its radiation pattern was mostly blocked. Ideally, the antenna should have been mounted pointing up in an open area on the aircraft. Another solution is to put better gain antennas and/or higher-powered amplifiers both on the ground and in the air.

For information on MLB Company and their UAVs, contact Stephen Morris at 650-966-1022 (office) or 650-757-5613 (cell). His e-mail address is smorris@spyplanes.com.

Y. TETHERED BALLOON

The tethered balloon is approximately 12 feet in diameter when filled completely with helium. Several tanks of helium are needed for operation of the balloon. It takes roughly an hour to fill the balloon completely with helium. Since the balloon was used on multiple days, it was kept filled overnight and tied down. This alleviated the need to constantly refill it. If there are winds over 15 mph, the balloon should be deflated overnight to eliminate any possible damage. While airborne, the balloon does not perform well in high winds either. Any wind over 20 mph, the balloon should not be flown to alleviate any possible damage. In addition, due to the constant movement of the balloon in high winds, any connectivity trying to be established is very unreliable.

The balloon can carry a payload of up to 50 pounds. As seen in Figure 4, the payload is located underneath the balloon. For the March testing, the payload contained an omni-directional antenna, access point, 1-Watt Amplifier, DC to AC power converters, and two Lithium batteries used as the power source. A research associate at NPS, Kevin Jones, built this payload.

To let out or bring in the balloon, an attached motor controlled a large reel of string. The balloon could reach an altitude of approximately 3,000 feet. To fly the balloon, a large open area was needed because high winds could cause the balloon to be pushed horizontal rather than vertical. Figure 81 displays the balloon while airborne.

Figure 82. TETHERED BALLOON WITH PAYLOAD UNDERNEATH

Z. FIELD TEST TEMPLATE

The following information is a template that was used in the writing of the field tests.

TEST PLAN and REPORT FORMATS

GENERAL: Ideally, an experiment is reported on in two documents, an *experimental plan* that lays the foundation, and an *experimental report* that tells what actually took place and what the results were. For this thesis work the authors did not produce elaborate experimental plans, so they moved some of the information into the report. The following outline is suggested. Parenthetical notes identify further explanation of information that is contained in the section.

1. Introduction

A. Introduce the team (who)

B. Purpose

C. The *real world* problem the experiment will help solve (what)

D. The specific questions the experiment seeks to answer

E. The Methodology (approach - how)

F. Anticipated Results

G. Scope of Experiment (why)

2. Experimental Design

A. Setup

B. Physical (location and time frame of experiment –when, and where)

C. Test subjects (technologies tested)

D. Schedule of Trials (planned schedule)

E. Assumptions

F. Statistical Design of Experiment (network diagram)

G. Instrumentation (equipment used for collecting data)

H. Testing & Pilot Trials (baseline results)

3. Data Description

A. Example of raw data

B. Data problems

C. Data table

4. Analysis (both: findings and analysis)

A. Findings

B. Analysis (summary of experiment)

5. Conclusions

A. Experiment Summary

B. Real world results of experiment

6. Recommendations

A. Changes to the Experiment

B. Continuation of the Experiment

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

ACE	Aviation Combat Element
ATC	Air Traffic Control
ATM	Asynchronous Transfer Mode
BLOS	Beyond Line of Sight
CAC2S	Common Aviation Comand and Control System
CE	Command Element
COC	Combat Operations Center
CoNDOR	Command and Control On the Move Network, Digital Over the Horizon Relay
CS	Communications Subsystem
CSSE	Combat Service Support Element
DASC	Direct Air Support Center
DOD	Department of Defense
DSU	Digital Switch Unit
EIGRP	Enhanced Interior Gateway Routing Protocol
EPLRS	Enhanced Position Locating and Reporting System
FSO	Free Space Optics
GCE	Ground Combat Element
GDDS	General Dynamics Decision Systems
GET	Generator, Environmental Control Unit, and Tent
GUI	Graphical User Interface
HF	High Frequency
HMMWV	High Mobility Multi-Purpose Wheeled Vehicle
IEEE	Institute of Electrical and Electronics Engineers
IMUX	Iridium Inverse Multiplexer
INE	In-Line Network Encryptor
IP	Internet Protocol
JTRS	Joint Tactical Radio System
LAAD	Low Altitude Air Defense
LAN	Local Area Network
LOS	Line of Sight
MAC	Media Access Control
MACCS	Marine Aviation Command and Control System
MAGTF	Marine Aviation-Ground Task Force
MAR	Mobile Access Router
MCSC	Marine Corps Systems Command
MCTSSA	Marine Corps Tactical Systems Support Activity
MEF	Marine Expeditionary Force
MRC	Mobile Radio Component
MRF	Mobile Research Facility
MSC	Major Subordinate Command
NLOS	Non Line of Sight
NOC	Network Operations Center
NPS	Naval Postgraduate School
ODU	Outdoor Mounted Unit

OFDM	Orthogonal Frequency Division Multiplexing
OIF	Operation Iraqi Freedom
OTH	Over The Horizon
PDS	Processing and Disply Subsystem
POP	Point of Presence
PRC	Portable Radio Component
RF	Radio Frequency
RFM	Radio Frequency Module
SCCP	Skinny Client Control Protocol
SDS	Sensor Data Subsystem
SIP	Session Initiated Protocol
SMART-T	Secure, Mobile, Anit-Jam, Reliable Tactical Terminal
SSID	Service Set Identifier
TACC	Tactical Air Command Center
TAOC	Tactical Air Operations Center
TCP	Transport Control Protocol
TDN	Tactical Data Network
TRC	Tactical Radio Component
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
UOC	Unit Operations Center
USMC	United States Marine Corps
USN	United States Navy
VHF	Very High Frequency
VoIP	Voice over Internet Protocol
WAN	Wide Area Network
WAP	Wireless Access Point

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Marine Corps Representative
   Naval Postgraduate School
   Monterey, California

4. Marine Corps Systems Command (Attn: Program Manager Operation Centers (PMM111), MAGTF C4ISR (PG12), and PM Communications (PMM122))
   Quantico, Virginia

5. Space and Naval Warfare Systems Command – Charleston
   (Attn: Dennis Gette and John Weed)
   Charleston, South Carolina

6. Director, Training and Education, MCCDC, Code C46
   Quantico, Virginia

7. Director, Marine Corps Research Center, MCCDC, Code C40RC
   Quantico, Virginia

8. Marine Corps Tactical Systems Support Activity (Attn: Operations Officer)
   Camp Pendleton, California

9. Marine Corps Warfighting Laboratory (Attn: C4)
   Quantico, Virginia

10. Office of Naval Research (Attn: Bill Bond)
    Arlington, Virginia

11. General Dynamics Decision Systems (Attn: ETCS and Unit Operations Center Program)
    Scottsdale, Arizona

12. Raytheon Integrated Defense Systems (Attn: CAC2S Program)
    San Diego, California

13. Joint Information Operations Center
    Lackland AFB, Texas

14. Headquarters Marine Corps (C4)
Arlington, Virginia